ELECTRIC ENERGY SYSTEMS AND ENERGY STORAGE

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION

OF THE

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ELECTRIC ENERGY SYSTEMS AND ENERGY STORAGE

TUESDAY, DECEMBER 8, 1981

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION,
Washington, D.C.

The subcommittee met, pursuant to call, at 1:50 p.m., in room 2325, Rayburn House Office Building, Hon. Marilyn Lloyd Bouquard (chairman of the subcommittee) presiding.

I. TRANSCRIPT OF HEARING

Mrs. BOUQUARD. The subcommittee will come to order.

Good afternoon, ladies and gentlemen. The subcommittee called this hearing to review the energy storage and electric energy systems research and development programs in light of recent information which indicates these two programs may be terminated by fiscal year 1983. Practically every single person in the United States depends on electricity for health purposes, safety, employment and comfort. This committee has recognized that fact and accordingly authorized over $6 billion over the past 4 years to develop new technologies for future electric generating plants. During that same period, however, the committee authorized only 2 percent of that amount for electric energy systems. The committee was of the opinion that a modest but stable long-term program would result in new transmission and distribution systems that could accommodate forthcoming increases in the demand for electric power. In spite of this carefully structured program, the administration believes 2 percent is excessive and that no Federal Government participation is necessary.

It is very obvious that the administration is dedicated to going out of the research business. The trends in aeronautics, fossil and solar energy and energy systems clearly indicate that short-term budget gains take precedence over long-term national investments.

The committee asked Mr. Joseph Tribble to be here today to explain the administration's energy storage and electric energy systems policy. However, Mr. Tribble had to go on a field trip. We were told Mr. Guy Fiske, Undersecretary for the Department of Energy, would take his place. But later, in Mr. Fiske's own words, he had "prior obligations." Mr. Fiske designated Dr. Maxine Savitz as the "logical spokeswoman."

Dr. Savitz' professional skills and experience are well known and very respected by this committee. We also appreciate Dr. Savitz' willingness to be a witness. But, for 2 months the committee had informed the Department of Energy that we did not want Dr.

Savitz as a witness because she is not the architect of this new policy.

It should also be noted that this committee also requested Mr. David Stockman to send Mr. Fred Khedouri as a witness to inform us about their basis for terminating these programs, but Mr. Stockman refused.

There isn't any member of this committee who does not appreciate and respect the administration's efforts to reduce the Federal budget. However, budgeting is one thing and economics is quite another. The purpose of research and development is to prepare for the future. It is to make investments now for tomorrow's benefits. What we do not sow, we shall not reap. What we do not sow, the Japanese, the French, the Germans, and many anxious other nations certainly will. As they grow strong in international trade, we will grow weak.

We have informally heard that the administration's new policy is to "let industry do it." In our opinion, that position fails to consider the severity and depth of economic problems that penetrate the private sector. I do not believe that all those problems were caused by the Federal Government. Hopefully, there is a logical and rational approach to research and development of energy systems, including storage and electrical systems, that paves a path to continuing prosperity.

We are happy to have with us today five executives who represent a cross section of industry and the utility companies. Our purpose is to hear what they believe they can or cannot do without Federal participation. Gentlemen, I thank each of you for being here today and affording us and the public an opportunity to hear your point of view on energy storage and electric systems. I will ask each of you to give us a 10-minute oral presentation, and after all of you have had that opportunity we will ask you some questions.

I want you to know that your written testimony will be made a part of the record, and we have also been informed that many informed citizens and executives have written us concerning their concern of the phaseout of Federal participation. After we review their testimony, the ones that we find pertinent, will be made a part of the record of these hearings.

We are going to begin with Dr. Schneider. Thank you very much for being with us.

STATEMENT OF THOMAS SCHNEIDER, ASSISTANT DIRECTOR OF ENERGY MANAGEMENT AND UTILIZATION DIVISION, ELECTRIC POWER RESEARCH INSTITUTE, PALO ALTO, CALIF., ACCOMPANIED BY RICHARD STEINER, DIRECTOR, POWER SYSTEMS DEPARTMENT

Mr. SCHNEIDER. Thank you, Madam Chairman, members of the subcommittee. Good afternoon. I am Tom Schneider, assistant director of the energy management and utilization division of the Electric Power Research Institute (EPRI), Palo Alto, Calif. On behalf of EPRI, I would like to thank you for the invitation to appear before this subcommittee and to testify on the continuing

role of the Federal Government in energy R. & D. and specifically on the electrical systems and energy storage areas.

Accompanying me is Mr. Richard Steiner, who is the director of the power systems department of EPRI's electrical system division, and Mr. Steiner is prepared to respond to questions on electrical systems R. & D. Mr. Steiner has more than 30 years' experience in electrical systems, working for both an electrical utility and a major equipment supplier prior to starting with EPRI.

I am prepared to respond to questions on energy storage. From 1977 to last year I was program manager, energy storage, at EPRI with responsibility for EPRI's programs in this area.

EPRI was established by the electric utility industry and is supported by voluntary contributions from electric utilities throughout the Nation. In 1981, EPRI's budget of approximately $250 million will go for support of research, development, and demonstration projects. In general, EPRI emphasizes research and development that will result in near- and intermediate-term benefits. Almost 70 percent of EPRI's efforts is focused on the near term, 25 percent of our efforts on the next generation of technology, while approximately 5 percent of our efforts is characterized as having a payoff beyond 20 years.

Since its inception, EPRI has worked with DOE and other Federal agencies sponsoring energy R. & D. We have carefully coordinated our research programs so that they are complementary, in order to avoid unnecessary duplications, and to fulfill the proper and appropriate roles for each of us.

In many cases this coordination has resulted in the sponsorship of joint projects. Examples of such jointly funded efforts include the fuel cell demonstration in New York City, the Exxon donor solvent project, the H-coal pilot plant, and the battery energy storage test facility in New Jersey. Obviously, any change in Federal energy R. & D. programs will have a serious impact on these joint programs of major national importance.

At the present time we do not believe that the private sector will pick up all of the significant research being deleted from the Federal program. This is particularly true in the area of energy research related to electrical energy use, production, and distribution.

The electric utility industry is a financially strained, regulated industry. This industry differs substantially from other energy industries. It currently is having considerable difficulty undertaking even the normal business investments required to provide reliable service. It is not in the position to undertake additional R. & D. beyond that which is already underway.

While the industry has continued its strong support for EPRI, it has been necessary to slow the growth of the institute's research budget. This budget is essentially fixed in constant dollars.

Further, the electric energy industry has some unique characteristics that discourage large investments in research and development. For example, the normal relationship between benefits and risks, which really encourage private sector investment in R. & D., does not really apply in the electric utility area. Being fragmented and regulated, the utility industry cannot undertake high-risk research and development projects and expect to reap a return.

Commissions typically do not provide for rates of returns adequate to encourage high-risk and costly R. & D. development investments.

This leads to examples in electrical systems and energy storage R. & D., which I will address in turn.

Electrical systems R. & D. continues to be an important area for the Nation. Utility construction, operating and maintenance costs continue to escalate. Electrical systems research provides sound scientific fact that will form the basis for higher capacity, more efficient, more reliable, yet lower unit cost energy delivery systems in the future.

EPRI's electrical systems research program is directed primarily toward short-term hardware developments. About 85 percent of the research support in this area is directed at the near-term industry needs. To fill a gap that exists in electric utility oriented research in the United States, with the understanding that the longer term research would be undertaken by the Federal Government.

We believe that there is a need for Federal participation in electrical systems R. & D. This role is concentrated in two areas: One, the high-risk, long-term research areas that would not normally be sponsored by private industry, and two, products of national value but requiring investments of such magnitude that it would not normally be recovered by private industry as a result of the R. & D. investment.

Examples in the first category of long-term research include the work on superconducting generators, cryogenics, and high-voltage AC and DC transimission above 600,000 volts. Underground transmission is a good example of the second category. Where needed, underground transmission is of great importance, but the value of this technology is not reflected in the volume of sales to an individual company which would be making the investment in the R. & D. to develop higher voltage underground transmission cable.

In the past, the electrical systems division of EPRI and the electrical energy systems of DOE have had programs of comparable size. The two organizations have worked together effectively, indeed, had a very strong and good working relationship. We feel this cooperation should be continued at close to the same level of effort. If this is not done, it will be difficult to fill the gap that results between what EPRI can accomplish in this area and what has been going on in the past as a result of the joint efforts.

Energy storage technologies is a second area of interest to the committee in this testimony. Energy storage technologies are required to provide a better coupling between energy supply and demand. This need applies to a wide range of applications in the transportation, residential, and industrial sectors. Thermal storage and in the electric utility industry pumped hydro, compressed air and battery energy storage as well as more advanced concepts energy storage, offer the benefits of reduction in oil and gas consumption through the substitution of energy from coal and uranium or the new renewable resources when they become available.

The most important benefit of energy storage is indeed the ability to substitute available domestic resources for scarce oil and gas. Typically, 2 to 3 million barrels of oil eqivalent can be saved for every 1,000 megawatts of energy storage installed in the utility

system. This happens primarily because we are putting more of that base load energy to work on the night shift.

Motivated by these benefits, EPRI has put in place a comprehensive energy storage program and will spend about $62 million over the next 5 years. During past years, EPRI's programs in energy storage has been closely coordinated with the Department of Energy's programs in both near and intermediate-term technology development efforts.

In recent months, EPRI and the utility industry has been shifting the project selection process and funding strategy to assure that the near-term and intermediate technology developments would be continued as DOE moves more toward the funding of longer term, higher risk efforts.

Earlier in this testimony we provided the basis for understanding that Federal participation is important in the future as well, because in this area, it is not really feasible for the private sector to displace the Federal funds that have been present. This applies particularly to energy storage. For example, the lack of industrial spending on R. & D. in electric vehicle batteries rests primarily on the fact that there is not a well-developed market for electric vehicles, and the fact that the narrow profit margins that exist in the battery industry makes technical shifts a high risk for the current battery manufacturers.

This argument applies equally to the utility load-leveling battery. Here not only is the energy storage battery a new technology there but it is indeed a new application. Electric utilities are not currently using any form of dispersed electrical storage or generation. Further, while the potential market is large, both the market is uncertain and the probability of success of any one battery system is low, typically less than 50 percent.

Similar arguments apply to the mechanical storage systems, where, in addition, we have the secondary problem that these are engineered systems, not manufactured products, so that an individual company cannot make an investment in a product and then reap a reward in the sale of that product. These are engineered systems and they are not manufactured in a factory.

In summary, a long history of cooperation has existed between the Federal and the EPRI energy storage programs. We believe that a national effort in this area of about $50 million a year on utility energy storage is appropriate, and would continue and maintain the healthy program that has been underway. The current EPRI program is about $8 million while the private developers are spending about $20 million per year. We believe it will be very difficult for the private sector to fill even a portion of the gap between what is a needed program and what level of funding appears to be available.

Overall, then, looking at both the electrical systems area and energy storage, I would like to conclude with two points. One is that we believe that there is a continuing Federal role for long-term high-risk electrical energy systems and energy storage research. While EPRI concurs with the effort to increase private sector energy R. & D., we are realists and recognize that increased investments at present are discouraged by the uncertainty of technical success, the weakness of the market and the long develop-

ment times. Therefore we cannot foresee rapid increase in private sector support for research and development in this area.

Second, EPRI is working to accommodate its programs to the changing direction in federally sponsored energy R. & D., but our ability to meet this challenge is limited by our essentially fixed budget. Improvements in the financial health of the utilities would do much to allow the industry to accommodate more of the changes that are being contemplated. Such improvements in the financial health of the industry will, however, take time, and hence the adjustments in the Federal support of R. & D. should not be made at the expense of the momentum and progress that is being made today in the ongoing programs in both electrical energy systems and energy storage.

[The prepared statement of Mr. Schneider follows:]

PREPARED STATEMENT OF THOMAS R. SCHNEIDER

Madame Chairman,

Good afternoon. I am Thomas R. Schneider, Assistant Director, Energy Management and Utilization Division of the Electric Power Research Institute (EPRI), Palo Alto, California. On behalf of EPRI I would like to thank you for the opportunity to appear before this Committee and present information on our perspectives on future energy R&D, the need for continuing federal government sponsored R&D and priorities for continuing with R&D in electric energy systems and energy storage. This testimony is in response to your invitation of November 24, 1981 directed to Mr. Richard Rudman, our Director of Information Services.

I will present a short summary of our official testimony and am prepared to respond to questions from the committee. Accompanying me is Mr. Richard Steiner, Director, Power Systems Department of EPRI's Electrical Systems Division who is prepared to answer questions on electrical systems R&D. Mr. Steiner has more than 30 years of experience in electrical systems working both for an electric utility and a major equipment supplier. I am prepared to answer questions on energy storage. From 1977 to last year I was Program Manager, Energy Storage for EPRI and was directly responsible for EPRI's energy storage R&D efforts. Prior to joining EPRI I worked in the electric utility industry and was principal investigator on the major joint ERDA (AEC)- EPRI project, "An Assessment of Energy Storage Systems Suitable for Use by Electric Utilities" which was completed in August of 1976 and provides the technical and economic basis for the direction of both EPRI and DOE's program in electric energy storage.

EPRI RESEARCH ACTIVITIES

The Electric Power Research Institute was established by the electric utility industry in 1973 to plan and manage a comprehensive research, development and demonstration program for the entire electric utility industry and its ratepayers. EPRI is supported by voluntary contributions from investor-owned, government-owned and cooperatively-owned electric utilities across the nation. In 1981, EPRI will expend approximately $250 million on research, development and demonstration to help ensure an adequate, environmentally acceptable supply of econ-

omical and reliable electricity. Its program spans electricity production, delivery and use. Our support is entirely from utilities. Based on over seven years of annually updated analysis of the outlook for energy in the U.S., EPRI remains convinced that electricity is now, and will continue to be, an important growing element in the U.S. energy picture.

In general EPRI emphasizes research and development that will result in near and intermediate term benefits. For example, almost seventy percent of the EPRI effort is focused on projects that should result in benefits to the utilities and their customers during the next ten years. Emphasis is placed on achieving improvements in the performance and availability of existing systems, conservation, load management and environmental control. Much of our electrical systems research is in this category. Twenty-five percent of our effort is devoted to next generation systems, such as fluidized bed combustion, gasification-combined sysle and the nearer term renewables having significant potential beginning in about 10-20 years. Approximately 5 percent of our work is characterized as having a payoff beyond 20 years. We believe that this approach complements the Federal research and development program which emphasizes longer term developments and more basic research.

EPRI AND FEDERAL R&D COORDINATION

Since its inception, EPRI has worked with the Department of Energy (and its predecessor agencies), the Nuclear Regulatory Commission,

the Environmental Protection Agency, and other Federal agencies with energy research and development responsibilities. We have carefully coordinated our programs to assure that they are complementary to each other to avoid duplication and to fulfill the roles appropriate to each of us.

The greatest degree of coordination between Federal programs and EPRI exists on the intermediate term technologies that can be of benefit during the 1990's. In many cases this coordination is accomplished by the joint support of large projects such as pilot plants, development facilities and demonstrations of new technologies. Today we are participating in several joint programs with various federal agencies. Examples of such jointly funded developments are the fuel cell demonstration in New York City, the EXXON Donor Solvent project, and the H-Coal pilot plant program and the Battery Energy Storage Test Facility in New Jersey. Essentially all of these efforts are at key intermediate stages of development and important progress is being made. Thus, any change in the Federal energy R&D program will have a serious impact on our work. Significant delays and loss of partially completed research and development work will undoubtedly occur.

CONTINUING NEED FOR FEDERAL GOVERNMENT SPONSORSHIP OF R&D

At the present time we do not believe that the private sector will be able to pick up the work that is being deleted from the Federal program. The electric utility industry is a financially

strained, regulated industry which differs significantly from other energy industries. It is having considerable difficulty undertaking even those investments needed to provide continuing reliable service. Hence, it is not in the position to undertake additional R&D beyond that which is currently underway.

While the industry has continued its strong support of EPRI, it has been necessary to slow the growth of the research program to an essentially fixed constant dollar level. Accommodating such a limitation at the same time that the Federal government has cut back its direct support of electricity-related R&D introduces major budget problems for the Institute.

In addition to the immediate problems associated with maintaining a reasonable rate of progress on important jointly supported research and development projects, we believe a continuing need exists for federal research and development on long range more exploratory technologies. Research and development on technologies such as nuclear fusion, breeder reactor, and superconductivity obviously require federal support.

A second category of research requiring continuing federal support includes high risk developments that cannot logically be completely funded by the private sector. In this case the electric energy industry has some unique characteristics that discourage large investments in research and development. For example, the relationship between benefits and risks, which encourage private

sector investments, does not apply to the electric utility industry. Being fragmented and regulated, it cannot undertake high risk research and development projects. Commissions typically do not permit rates of return commensurate with an investment in high risk and costly research and development.

Further, the large industrial suppliers to the electric utility industry are currently also constrained in their ability to support R&D because of declining sales, future uncertainties of the market and difficulty of obtaining sufficient return on the investments to justify the expenditures.

Today I wish to address two specific program areas that are currently coordinated with the Department of Energy activities: Electrical Systems and Storage Technologies.

ELECTRICAL SYSTEMS R&D

Electrical Systems research and development is more critical today than ever before. Utility construction, operating and maintenance costs continue to escalate. Competition for land and capital resources increasingly affect delivery system design. Aesthetic and environmental pressures to place the delivery system underground continue. Future Electrical Systems research will provide the additional technology needed to define right-of-way and line design requirements for utility delivery systems. These technical requirements rest on prudent application of engineering

principles, new technology and experience. Electrical Systems research provides sound scientific facts that will form the basis for higher capacity, more efficient, more reliable, yet lower unit cost delivery systems needed in the future.

EPRI electrical systems research is primarily oriented toward short-term hardware developments which generally have a high probability of success. Therefore about 85% of the research support in this area is directed to near-term industry needs that will be used within the next five- to ten-year time period. This emphasis on short-term hardware-oriented developments is based on two factors: (1) It fills a gap that exists in electric utility oriented research in the United States, and (2) an understanding that longer term, higher risk research would be carried out by the Federal Government.

In addition to the EPRI work, research and development is undertaken by the individual utilities and the electrical systems equipment suppliers. Individual utility projects usually concentrate on operational requirements, improvements in efficiency, or cost reduction. These efforts seldom include hardware-oriented research.

Traditionally electrical systems hardware research in the United States has been performed by the electric equipment manufacturers. During the past 10 years, however, these manufacturers have significantly de-emphasized their R&D involving the development of new technologies. In addition, there is a trend for the U.S. equipment manufacturers to be absorbed by foreign corporations. The

R&D is then transferred to the new foreign parent company. These factors have substantially reduced new technological breakthroughs in our industry. If this trend continues, the available laboratories and staffs of qualified personnel will be reduced to a point where necessary R&D would have to be delegated to foreign manufacturers.

We believe that there is a need for Federal participation in electrical systems R&D-oriented research. This role, however, should be concentrated in two areas that would otherwise not receive sufficient attention. These areas are: (1) high risk or long range research that would not be sponsored by private industry, and (2) projects of national value but requiring funding of such magnitude that it could not be recovered by private industry.

Examples in the first category include research on superconducting generators, cryogenic cables and ac and dc transmission above 600-kV. Underground transmission is an example of the second case. Where needed, underground transmission is of great importance but the volume of the business tends to be such that private industry cannot afford an aggressive development program.

In the past, the Electrical Systems Division of EPRI and the Electrical Energy Systems of DOE have had annual budgets of comparable size. The two organizations have enjoyed an excellent working relationship and have developed research programs that were complementary. In this planning process, long-term, high

risk projects were funded by DOE. We feel this current division of research is reasonable. If this is not done, it will result in a gap in needed technology development that, at present, EPRI, due to financial constraints, will not be able to absorb.

ENERGY STORAGE RESEARCH

New energy storage technologies are required to better couple energy supply with demand in a wide range of applications: transportation (batteries/flywheels), residential (thermal energy storage), industrial (thermal energy storage/batteries), and electric utility (pumped hydro/compressed air/batteries/superconducting magnets). Energy storage provides the potential to displace oil (and gas) based fuels by coal and uranium, in transportation through the electric vehicle and in electric utilities by using stored base-load energy to meet peak demands.

The most important benefit of energy storage that will accrue to the consumer of electric energy, the electric utility industry, and the country as a whole is the conservation of petroleum or gas: 2-3 million barrels of oil equivalent can be saved per year for every 1000 MW of storage installed. About 100×10^6 barrels per year could be saved in the year 2000 if energy storage systems now being developed become available in time for deployment by electric utilities. Utility energy storage could also have other benefits: environmental effects would be reduced and fewer transmission lines may be required. The costs of electricity would

likely be lower since utilities could use storage to utilize lower cost fuels and achieve better utilization of baseload power plants. Finally, the reliability of electric service could be enhanced, especially if networks of small dispersed storage devices, such as batteries, could be deployed on future electric power systems.

Current EPRI Effort

Motivated by these potentially major benefits, EPRI has put in place a comprehensive energy storage program that will expend about $62 million over the 1981-1985 time frame; this program is discussed on pp. 498-509 of the EPRI 1981-1985 R&D Plan, EPRI P-1726-SR. During past years, this EPRI program has been carefully coordinated with the energy storage programs funded by the Department of Energy. In recent months, EPRI and the utility industry have been shifting their project selection and funding strategy to assume more of the near-term, hardware-oriented efforts as DOE has moved toward the funding of the higher risk, longer term activities. For instance, responsibility for the development and verification of new components for pumped hydro is now being assumed by the private sector, and the transition of near-term work in compressed air storage to the private sector is essentially complete. EPRI, also, is assuming a larger role in the evaluation of prototypical battery storage devices.

Need for Continuing Federal Sponsored R&D

Substantial technical progess is required before the full benefits

of several of the key energy storage concepts can be achieved. DOE should continue to share in the R&D that is required to reduce the technical risks to acceptable levels and to produce the needed technical advances if energy storage technologies are to be deployed by the private sector.

Earlier in this testimony we provided the broad basis for understanding why federal participation is essential. In energy storage research it is appropriate to expand our comments. Currently, there really is not an existing market for these technologies. These are new technologies entering a new market -- not the simple displacement of an existing product with an improved product, but a new product being used in a new way. For example, the lack of industrial spending on R&D for electric vehicles (and batteries) rests primarily on the fact that there is no well-developed market for electric vehicles and the fact that narrow profit margins make technological shifts a high risk. This argument applies equally to the utility load leveling battery market. Not only is the energy storage battery a new technology, but it is a new application. Electric utilities are not currently using any form of dispersed electrochemical storage or generation. Further, while the potential market is large, both the market is uncertain and the probability of success with any one battery system is low -- typically less than 50%.

For the mechanical storage technologies our earlier arguments regarding the lack of reward for electric utility risk taking apply. Here we also have the problem that these are engineered systems --

not manufactured products -- and it is the end user who must be motivated to take the risk. Further, the lack of benefits being concentrated so that an organization doing the R&D can reap its reward further hampers private sector initiative.

Broad Outline of Needed Federal Program

A significant amount of research is required to bring the storage technologies being developed to their full potential. This point and the need for DOE support can be illustrated by describing the status of two of the high priority research areas.

- Advanced compressed-air energy storage (CAES) concepts offer promise of reducing oil use but further work is required on thermal storage and subsystem integration to reduce the substantial technical risks. Federal support is needed in this area and other, higher-risk/high-payoff aspects of CAES, including specifically the evaluation of aquifers as potentially low cost air storage reservoirs. In selectively supporting these areas of R&D, the Government can take advantage of strong private-sector support of near-term CAES technology which should result in a resolution of the basic turbomachinery issues.

- Batteries offer benefits (such as low emissions, rapid response, high part-load efficiency, and modularity) that go well beyond those of the larger storage technologies. However, load leveling batteries will require another 5-10 years of intensive development and evaluation in representative sizes before

they will be ready for commercial deployment. Sodium-sulfur, zinc chloride, and zinc bromide batteries all have shown exciting progress in the past few years. EPRI is funding this area at a $5 million annual rate, and developers are providing about $10 million per year. In our opinion a healthy national program in this area should be funded at about $30 million.

- Advanced batteries and applied electrochemistry support is urgently required from DOE since the private sector has had to shift its support from these areas toward near-term work.

- Key questions concerning reliability, life and system integration of new battery technologies cannot be answered until experimental battery systems of modest size are evaluated in the Battery Energy Storage Test (BEST) Facility. This facility has been funded jointly by DOE, Public Service Electric and Gas and EPRI. EPRI has budgeted $1-2 million for its 1982 participation. To achieve the full potential of the facility the total national funding should be about $3 million per year.

- Finally, more advanced or long range utility storage concepts, which cannot be adequately supported by EPRI, such as superconducting magnets, thermal storage, hydrogen, etc., warrant continued investigation.

- Development of energy storage for use by the consumer of electricity merits special attention also. Here we have the opportunity to directly shift energy use from on-peak oil and gas to off-peak coal and nuclear. This requires, however, extensive development of new materials -- primarily for thermal energy storage. We believe that the support of this basic, long range research area is appropriate for DOE.

In summary, a long history of cooperation has existed between the Federal programs and EPRI on the development of the storage options. We estimate that a healthy national effort in this area would require about $50 million a year. The current EPRI program on storage systems is about $8 million per year and the developers are expending about $20 million per year. We believe that it will be difficult for the private sector to bridge this gap.

CONCLUSION

In conclusion, we wish to stress the following points:

* We believe that a continuing federal role does exist in long term high risk Electric Energy Systems and Energy Storage research. While EPRI concurs with the efforts to increase private sector energy R&D, we are realists in recognizing that increased investments are discouraged by the uncertainty of technical success, the weakness of the market and the long development times. Therefore we cannot foresee rapid increases in industry support for research and development at this time.
* EPRI is working to accommodate its program to the changing direction in federally sponsored energy R&D but our ability to meet this challenge is limited by our essentially fixed budget. Naturally improvements in the financial health of the utilities could do much to allow the industry to accomodate some of the changes that are being contemplated. Such improvements will, however, take time and, hence, adjustments in federal support of R&D should consider the momentum and progress being made in the on-going programs.

Mrs. BOUQUARD. Thank you very much, Dr. Schneider, for your testimony. We appreciate the input that EPRI makes in our hearings.

Mrs. BOUQUARD. We would also like to welcome Mr. Peter Lewis, who is with the Public Service Electric & Gas Co. of New Jersey. Thank you for being with us. Please proceed with your testimony.

[The biographical sketch of Mr. Lewis follows:]

Peter A Lewis
Manager - Applied Systems
Research and Development
Public Service Electric and Gas Company
80 Park Plaza
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EXPERIENCE

Mr. Lewis was employed by PSE&G in June 1959 as a Cadet Engineer and has held various positions in the System Planning and Research and Development Departments. He is currently Manager-Applied Systems, Research and Development, and has served as Program Manager for design, construction, testing and acceptance of the Battery Energy Storage Test (BEST) Facility which is being built under contract with the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI). He is responsible for preparing a development and demonstration program for the Company with expenditures estimated to be $40 million over a five-year period. This research program includes the assessment of new technologies, demonstration of advanced energy conversion techniques, improvements to current equipment used in energy conversion, transmission and distribution, reduction of the impact of supplying energy services on the environment, and increasing the efficiency of energy utilization. He has testified on renewable sources and energy alternatives for New Jersey before the Energy Conservation Subcommittee of the New Jersey Assembly Energy and Natural Resources Committee. He has also appeared as a PSE&G witness before the New Jersey Public Utilities Commission (NJPUC) as part of a rate proceeding and during an inquiry into the energy crisis.

Prior to 1971, Mr. Lewis was a Senior Engineer in the Transmission Planning Division with responsibilities for planning short and medium range transmission facilities, including interconnections with neighboring utilities. He was designated Chairman of a five company planning group responsible for developing transmission plans for the installation of five nuclear units at three locations in New Jersey and Pennsylvania. He also investigated and evaluated the application of AC and DC overhead and underground transmission ties to strengthen the interconnected systems of the Northeast. He presented expert testimony before the NJPUC in connection with obtaining right-of-way and relief from local zoning ordinances for construction of 500 kV transmission lines through New Jersey.

STATEMENT OF PETER A. LEWIS, PE, MANAGER, APPLIED SYSTEMS, RESEARCH, AND DEVELOPMENT, PUBLIC SERVICE ELECTRIC & GAS CO., NEWARK, N.J.

Mr. LEWIS. Thank you, Madam Chairman. Good afternoon. I am Peter A. Lewis, manager-applied systems, research and development, for Public Service Electric & Gas Co. [P.S.E. & G.], located in Newark, N.J. On behalf of the company, I wish to thank you for the opportunity to appear before this committee and present information on energy storage, electric energy systems and limits of utility funding of energy research, development and demonstration programs.

Public Service Electric & Gas Co., is New Jersey's largest energy utility, supplying electricity and gas to over 5 million people, approximately three-fourths of the State's population. The company's service area stretches across the State's industrial corridor from the New York State line to below Camden in southwestern New Jersey.

P.S.E. & G. is a pioneer in developing and applying new energy concepts designed to provide consumers with safe, adequate and reliable electric service at the lowest possible cost, and with minimum environmental impact.

A number of projects in which P.S.E. & G. has pioneered are listed in the formal testimony submitted earlier. Some of these projects related to today's hearings are the construction of the first 230,000-volt transmission ring in the late 1920's which connected P.S.E. & G., Philadelphia Electric Co., and Pennsylvania Power & Light Co. This was an early project of the founding members of the Pennsylvania-New Jersey-Maryland Interconnection [PJM] and made the economic transfer of power possible among these companies.

Another project in which we have been participating is in the development of fuel cell powerplants.

The operation and testing of fuel cell powerplants connected to a utility grid was first demonstrated at our city dock substation in 1972.

P.S.E. & G. has made a major commitment to reducing the use of petroleum fuels which, in our service territory, come primarily from abroad. This reduction is being accomplished through the construction and operation of nuclear powerplants which will provide a large portion of our customer electrical needs through the end of the century. We are also investigating ways to increase the utilization of coal as a replacement for expensive foreign oil.

My formal testimony briefly summarizes three areas related to electric utility and Federal Government coordination of electric energy systems and energy storage research. These areas include:

The evolution of utility research program coordination;

The need for programs to support research directed at reducing costs and providing reliable power;

The limits of utility funding of research, development and demonstration [R.D. & D.] programs.

Dr. Schneider described the role of EPRI and agencies of the Federal Government in coordinating electric utility R.D. & D. and has outlined the need for continuing strong support by the Federal

Government in electrical systems and energy storage programs. In general, all of the programs described by Dr. Schneider have the potential for reducing the cost of electric generation and supply while at the same time making the electric system more efficient and reliable.

In the interests of time, I will present a brief summary of the BEST facility program in which we have been participating from its inception, and also describe briefly some of the limits of utility funding of R.D. & D. programs.

The BEST facility was constructed by P.S.E. & G. under contract with DOE and EPRI. The purpose of this unique lab is to serve as the focus for development of advanced battery systems for energy storage in electric utility systems. Planning for construction and operation of this laboratory included joint funding by the Federal Government and the electric utility industry through EPRI.

In addition, P.S.E. & G. supplied as its portion of the cost sharing, the site and the building to house facility equipment. The sources of funding for this project are the Federal Government through DOE 38 percent, electric utility industry through EPRI 38 percent, and Public Service Electric & Gas Co., 24 percent, for a total of $19.4 million. Approximately 62 percent of the total funding is being provided by industry.

Batteries to be tested at the facility are being developed under separate contracts with EPRI and DOE. In many cases these contracts include cost sharing by battery developers. This battery development and testing program represents a well-coordinated effort by the industry, battery developers and the Federal Government to insure that all phases of project development from research through prototype testing to demonstration of a near commercial product are carried out in a cost-effective manner.

Continuation of this well planned and coordinated program was in doubt earlier this year due to delays in processing a modification to the three-part BEST facility contract. Failure to continue with the BEST facility project at this time could result in loss of a large utility investment in expensive experimental equipment.

The programs described call for joint participation by Government, utilities, and manufacturers and are based on coordinated planning with identified means for sharing costs for various program activities. Indeed, if any participant unilaterally withdraws support, the effectiveness of the program is reduced.

Currently, EPRI serves as the major focal point for coodinating and conducting electric utility related research. EPRI is supporting the development of new concepts that can be readily applied to utility systems as well as improving current technology. To do this, EPRI is providing about $500 million to support joint demonstrations valued at approximately $1.6 billion. Utility companies, manufacturers and the Federal Government, which has several branches that operate as utilities, make up the balance in either money, facilities or services.

In addition to supporting EPRI, many utilities such as P.S.E. & G. have internally funded R.D. & D. programs. However, because of risks in some projects over which the industry has no control, it is not possible for the utility industry to assume the entire financial burden of developing new technologies.

The Director of the Energy and Minerals Division of the General Accounting Office prepared a memorandum to the chairman and ranking minority member of this committee which analyzed the role of Federal funding for electric utility R.D. & D. projects.

In this memorandum, it was pointed out that the electric utility industry has research and development efforts but because of financial problems, risks associated with demonstration, and the large investments required, utilities will not carry out demonstrations on their own in all technology areas.

In the same memorandum, it was pointed out that if the Federal Government withdraws support from programs currently underway, it is unlikely that EPRI or the utilities can provide the necessary support. Fuel cells was cited as an example. This is a technology which could provide electric utilities with efficient power if demonstrated to be economical and reliable.

The DOE, which initiated and supported a fuel cell project on the Consolidated Edison Co. system, proposed Federal funding of the project be discontinued even though the facility was ready for operation and testing. It was assumed that industry could provide the $12 million necessary to complete the project.

However, industry representatives stated that only about $6 million could be committed to operate and test the facility, and because of tight financial conditions, the project would probably be terminated unless Federal funding was provided.

The Federal policy to fund only long-term high-risk research does not appear to be an effective way of supporting R.D. & D., particularly for electric utilities. This position does not consider the financial problems currently faced by utilities.

Today, average utilities sales amount to about half of total assets, whereas in manufacturing industries, sales average double total assets. Consider that even under low-growth forecasts investor-owned electric utilities will need to generate many billions of dollars over the next 10 to 15 years just to build new capacity. Most of the capital will have to be raised in times of high interest rates, with profits held down by regulators trying to keep consumer electric bills low.

The lack of profit not only shrinks the amount of cash available for new construction but also hinders utilities' ability to service debt. For utilities, the pretax interest coverage ratio, or the number of times earnings cover the interest expense has decreased from about 4 in the 1960's to levels approaching 2 in 1981. This has contributed to the downgrading of bond ratings of nearly 100 utilities and will ultimately result in higher interest charges which are paid by the customer.

In addition, with low coverage ratios, many utilities are prohibited from issuing new bonds due to restrictions written into existing indentures.

The low coverage ratio also indicates that a large part of utility earnings is used to pay fixed interest expenses. Most of the remainder of the earnings is used to pay taxes and dividends. There is little left to finance new construction and support R.D. & D.

Another factor to consider is that a nonregulated industry can make and keep more profit and determine how to price and sell its products. Utility improvements in operations resulting in lower

costs are returned to consumers through the rate structure. Allowed rates of return to utility investors are not commensurate with the level of risk associated with developing and demonstrating new technologies.

In conclusion, I would like to emphasize that the electric utility industry has been responsive to national needs in formulating research, development, and demonstration programs. This is evident in changes that have taken place in nuclear energy, environmental quality and conservation of energy. To continue these programs will require the full support and cooperation of the Federal Government.

Because of the benefits that can be realized by consumers and taxpayers through the early demonstration of new technologies, the Federal policy toward electric utility R.D. & D. should be reviewed. The electric utility industry can adjust its programs to assume a specific role that may no longer be seen as that of the Federal Government. However, in adjusting to any new position, it is important that a transition period be established during which a coordinated change from Government-funded programs to industry-funded programs can be planned.

During this transition period, projects should be reviewed and areas identified where the Federal Government has a role in supporting development of new technologies. It is very detrimental to national goals to terminate ongoing programs for the sole objective of achieving a reduction in cost when the long-term consequences of not having those programs may be to increase future expenditures or result in a general decrease in national productivity.

We believe the joint participation of the Federal Government and utility industry in past research programs has been productive, and that it can continue to be productive in the future if properly coordinated. At P.S.E. & G. we are prepared to work with representatives of Government to plan the future implementation of energy research, development, and demonstration programs.

Madam Chairman, thank you very much again for your interest in electric energy system R.D. & P. and for this opportunity to appear before you today.

[The prepared statement of Mr. Lewis follows:]

PREPARED STATEMENT OF PETER A. LEWIS

PURPOSE OF TESTIMONY

Good afternoon. I am Peter A Lewis, Manager - Applied Systems, Research and Development, for Public Service Electric and Gas Co. (PSE&G), located in Newark, NJ. On behalf of the Company, I wish to thank you for the opportunity to appear before this Committee and present information on energy storage, electric energy systems and limits of utility funding of energy research, development and demonstration programs.

Public Service Electric and Gas Company (PSE&G) is New Jersey's largest energy utility, supplying electricity and gas to over five million people; approximately three-fourths of the State's population. The Company's service area stretches across the State's industrial corridor from the New York state line to below Camden in southwestern New Jersey.

PSE&G is a pioneer in developing and applying new energy concepts designed to provide consumers with safe, adequate and reliable electric service at the lowest possible cost, and with minimum environmental impact. Typical of projects in which PSE&G has pioneered are the following:

- The construction of the first 230,000-volt transmission ring in the late 1920's which connected PSE&G, Philadelphia Electric Company, and Pennsylvania Power and Light Company. This was an early project of the founding members of the Pennsylvania - New Jersey - Maryland Interconnection (PJM) and made the economic transfer of power possible among these companies.
- The testing of a wind energy system, at our Burlington Generating Station, using a Madaras rotor in the early 1930's.
- The installation and operation of Mercury Boilers, at our Kearny Generating Station, to improve thermal cycle efficiency during the late 1930's.
- The extension of boiler steam conditions to higher operating temperatures and pressures was applied to generating station design during the late 1940's and early 1950's.
- The installation of the first multiple unit gas turbine generator during the late 1960's.
- The operation and testing of fuel cell power plants connected to a utility grid was first demonstrated at our City Dock Substation in 1972.

PSE&G has made a major commitment to reducing the use of petroleum fuels which, in our service territory, come primarily from abroad. This

reduction is being accomplished through the construction and operation of nuclear power plants which will provide a large portion of our customer electrical needs through the end of the century. We are also investigating ways to increase the utilization of coal as a replacement for expensive foreign oil.

My testimony briefly summarizes three areas related to electric utility and Federal government coordination of electric energy systems and energy storage research. These areas include:

- The evolution of utility research program coordination;
- The need for programs to support research directed at reducing costs and providing reliable power;
- The limits of utility funding of research, development and demonstration (RD&D) programs.

In addition, throughout my testimony I will intend the word utilities to imply electric utilities, although, many of the topics discussed here apply to other types of utilities.

EVOLUTION OF UTILITY RESEARCH PROGRAM COORDINATION

Traditionally, utility companies have worked cooperatively with manufacturers of equipment used in energy conversion, transmission, distribution and utilization to develop more effective and reliable systems and equipment, with the idea of reducing costs to consumers. This type of cooperation has been very successful in bringing about the early commercial introduction of new concepts in utility applications. The cost of manufacturers' RD&D programs was included in the price of the ultimate product. While this arrangement produced important advances, there were several disadvantages including:

- The lack of a comprehensive utility system RD&D program plan to guide manufacturers;
- The neglect of longer-term RD&D because manufacturers' efforts were directed toward projects that would produce marketable products in the near-term to maximize return on investment;
- The increase in manufacturers' product cost, due to the added RD&D cost, which resulted in a deterioration of competitive position.

During the late 1960's and 1970's virtually all U.S. manufacturing industries reduced the proportion of RD&D allocated to basic research. This was partly a result of inflation, which discouraged long-term projects; and heightened concern for the short-term effects of RD&D on profits. Even today, according to a National Research Council (NRC) study, research spending in the United States has barely reached the 1967 level in terms of real dollars. I might add that the same Council report warns that the U.S. may lose its lead in technology "...if support of research as a fraction of gross national product continues to decline as it rises in some of the countries that are some of our most successful competitors". The impact of this may be decreased American productivity and further increases in competition from abroad which may cause higher unemployment.

Also during this period, members of the electric utility industry recognized that reliance on manufacturers for RD&D was not providing the technical advances needed to meet the demands of rapidly expanding utility systems and did not give the control needed to coordinate and direct research activities. It was felt that utilities had an obligation to take the future more into their own hands. Therefore, to

bring about greater coordination of research activities, industry leaders formed the Electric Research Council. This Council was comprised of investor-owned utilities, rural cooperatives, municipal electric systems and agencies of the Federal government including the Tennessee Valley Authority and the Department of Interior. Through the Electric Research Council several programs were initiated and coordinated with agencies of the Federal government. Two major programs that resulted from this early effort were development of underground transmission cables and initiation of battery research that would lead to the development of load-leveling batteries. More information about these programs will be provided later.

Another activity of the Electric Research Council was the appointment of a Task Force to study the research and development goals for the electric industry through the year 2000. The results of this Task Force investigation were published in June 1971 and included a recommendation that the utility industry form an Electric Power Research Institute (EPRI). This recommendation was accepted by the Board of Directors of the Electric Research Council and in March 1972, EPRI was incorporated in Washington, DC.

As indicated earlier, since the mid 1960's, the industry has coordinated RD&D programs with the Federal government. Early coordination of these programs was principally with agencies responsible for the production or marketing of electrical energy. With the creation of EPRI, coordination has been expanded to include many agencies including the Department of Defense, National Aeronautics and Space Administration, Environmental Protection Agency, Department of Energy, (DOE) and Nuclear Regulatory Commission.

NEED FOR INDUSTRY AND GOVERNMENT RD&D PROGRAMS

Thus far I have referred to the electric utility industry as if it were a homogeneous entity. It is not. The industry is made up of approximately 3600 organizations of various sizes serving diverse areas from highly industrialized cities to rural regions with sparse population. In 1980, electrical energy used in the United States was generated:

- 78% by Investor-owned utilities
- 10% by Federal agencies
- 9% by Municipal and other government agencies.
- 3% by Cooperatives

As you can see, the Federal government is a part of the utility industry and provides a portion of the electric energy used in the United States.

Today the technical challenges confronting all segments of utilities can be generally grouped in the following categories:

- Resource Development
- Energy Conversion
- Transmission and Distribution
- Energy Utilization and Conservation
- System Integration and Control

Throughout these categories there are broad concerns relating to environmental impact, health, safety and reliability of supplying power to the consumer. These concerns must also be addressed while developing new technologies.

In these general categories, programs to develop technologies and address these concerns have been initiated through the interaction of

utilities, DOE, EPRI and utility equipment manufacturers. Information from these programs is used in many ways, not only by organizations that directly support the programs, but also by state and Federal regulatory agencies, legislative bodies, and individuals responsible for formulating policy.

The Electric Energy Systems (EES) Division of DOE has the sole Federal responsibility for performing electric network RD&D from a systems point of view. Because of this responsibility, EES is the DOE Division which has the most direct contact with utilities.

The primary objectives of EES programs are to:

- Provide advanced technology options to help ensure that the nation's electric energy systems will operate reliably and economically under all conditions, including national emergencies;
- Broaden the capability of domestic electric energy supply sources; and
- Provide a central source for impartial and objective information on electric system technology.

The EES Division has provided leadership in assessing the benefits of emerging technologies and determining the requirements for successful integration with the electric systems. The Division manages three program areas:

- Generation and Storage Applications which includes application and testing of advanced batteries for electric energy storage, compressed air and underground pumped-hydro storage.
- Power Delivery which includes development of underground and overhead transmission systems to increase the capability of

existing and future transmission line corridors and improve transmission efficiency and reliability.

- System Architecture and Integration which includes development of equipment and methods to:
  - Integrate dispersed generation such as solar and wind systems with the electric network;
  - Improve systems controls; and
  - Manage customer demand.

WHAT THESE PROGRAMS MEAN TO THE UTILITY AND THE PUBLIC

In general, all of these programs have the potential for reducing the cost of electric generation and supply and, at the same time, making the electric system more efficient and reliable. As an illustration, let's look at the concept of energy storage or load-leveling.

Electric utilities produce electricity on demand and they do this by installing combinations of generating plants which operate to satisfy a certain part of the load. In general, during off-peak periods, which occur at night, electricity is mostly produced by nuclear and coal generating facilities. As the load begins to increase until it peaks sometime during the day, oil-fired electric generation is added to supplement the nuclear and coal generating facilities. A problem which utilities face is that at night, during the off-peak period, they are unable to make full use of the low-cost energy available from nuclear and coal-generating equipment. With energy storage, utilities can make full use of this equipment by producing electricity and storing it for use later during the high demand period.

Therefore, energy storage has the potential for replacing oil-fired generation with coal or nuclear generation. Currently there is only one well established method of storing energy which is known as pumped-hydroelectric storage. This method has limited application because of environmental concerns and the relatively small number of available sites.

In July, 1976, PSE&G completed a research contract with EPRI and the Energy Research and Development Administration (ERDA) now DOE. This cooperative industry/government study calculated the potential role of energy storage in future electric utility systems and the results provided an impartial assessment of energy storage technologies that have potential utility applications. It was determined from this study that the amount of on-peak energy that could be supplied by generation available at off-peak times on U.S. electric utilities is 5% of the total electric energy produced.

An additional conclusion of the energy storage assessment was that proposed advanced battery systems could be developed that would be sufficiently compact, economically attractive, and environmentally acceptable to be suitable for dispersed siting throughout utility systems. The study recommended continued RD&D be devoted to these systems to seek improvements in battery life and development of low-cost manufacturing processes. This finding launched the development programs for advanced batteries and the program leading to construction of the National Battery Energy Storage Test (BEST) Facility.

The BEST Facility was constructed by PSE&G under contract with DOE and EPRI. The purpose of this unique laboratory is to serve as

the focus for development of advanced battery systems for energy storage in electric utility systems. Planning for this facility included joint funding by the Federal government and the electric utility industry through EPRI. In addition, PSE&G supplied as its portion of the cost-sharing, the site and the building to house facility equipment. The sources of funding for this project are:

o Federal Government through DOE	$ 7,400,000	38%
o Electric Utility Industry through EPRI	$ 7,400,000	38%
o Public Service Electric and Gas Company	$ 4,600,000	24%
	$19,400,000	100%

Batteries to be tested at the facility are being developed under separate contracts with the EPRI and DOE. In many cases these contracts include cost-sharing by battery developers. This battery development and testing program represents a well coordinated effort by the industry, battery developers and the Federal government to ensure that all phases of project development from research through early prototype testing, to demonstration of a near commercial product are carried out in a cost effective manner. Continuation of this well planned and coordinated program was in doubt earlier this year due to delays in processing a modification to the three party BEST Facility contract. Failure to continue with the BEST Facility project at this time could result in loss of a large utility investment in experimental equipment.

The power delivery program is another example of the type of benefits that may be realized through Federal support of EES programs.

Today's transmission system now links virtually all parts of the United States. As power system loads increase, the need to transfer larger blocks of power occurs. If the present technology for transmitting bulk power doesn't improve, there will be a greater need for transmission rights-of-way. This raises concerns about competition for land use, particularly in heavily populated areas, and associated safety and aesthetic issues. Improvements in bulk power delivery technology will reduce the costs of providing electric power to the public by increasing the productivity of the plant and equipment already in service and through better utilization of existing rights-of-way.

Research programs which the DOE has underway in joint projects with industry will help to foster these technology improvements by:

- Allowing more efficient operation and control of large interconnected systems to prevent regional power shortages and to accommodate new dispersed technologies.
- Developing advanced transmission systems that possess power delivery capabilities at least four times those of existing systems.
- Providing technical solutions to relieve transmission corridor acquisition problems.
- Developing transmission systems which can satisfy environmental requirements as well as deliver electric energy efficiently over long distances.

During the planning of the energy storage and power delivery programs, the national policy was to encourage development of new energy concepts so that they could be brought to the commercial stage of development early and thereby help increase national productivity and encourage American industry to compete in world markets. The programs described call for joint participation by government, utilities and manufacturers, and are based on coordinated planning with identified means of sharing costs for various program activities. Indeed, if any participant unilaterally withdraws support, the effectiveness of the program is reduced.

THE FUTURE OF UTILITY RD&D

Currently, EPRI serves as the major focal point for coordinating and conducting electric utility related research. EPRI is supporting the development of new concepts that can be readily applied to utility systems as well as improving current technologies. To do this, EPRI is providing about $500 million to support joint demonstrations valued at approximately $1.6 billion. The Federal government, utilities and manufacturers make up the balance in either money, facilities or services. In addition to supporting EPRI, many utilities have internally funded RD&D programs. However, because of risks in some projects over which the industry has no control, it is not possible for the utility industry to assume the entire financial burden of developing new technologies. On September 28, 1981, J. Dextor Peach, Director of the Energy and Minerals Division of the General Accounting Office, forwarded a memorandum to the Chairman and ranking minority members of this Committee which analyzed the role of Federal funding for electric utility RD&D projects. In this memorandum it was

pointed out that the electric utility industry has research and development efforts but because of financial problems, risks associated with demonstration, and the large investments required, utilities will not carry out demonstrations on their own in all technologies.

In the same memorandum it was pointed out that if the Federal government withdraws support from programs currently underway, it is unlikely that EPRI or the utilities can provide the necessary support. Fuel cells, a technology which could provide electric utilities with efficient power if demonstrated to be economical and reliable, serves as an example. The DOE, which initiated and supported a 4.8-MW fuel cell project on the Consolidated Edison Co. system, proposed that Federal funding of the project be discontinued even though the facility was ready for operation and testing. It was assumed that industry could provide the $12 million necessary to complete the project. However, industry representatives stated that only about $6 million could be committed to operate and test the facility and because of tight financial conditions, the project would probably be terminated unless Federal funding was provided.

The Federal policy to fund only long-term, high risk, research does not appear to be an effective way of supporting RD&D, particularly for electric utilities. This position does not consider the financial problems currently being faced by utilities. Today, average utility sales amount to half of total assets whereas in manufacturing industries sales average double total assets. Consider that even under low-growth forecasts, investor-owned electric utilities will need to generate many billions of dollars over the next 10 to 15 years

just to build new capacity. Most of the capital will have to be raised in times of high interest rates, with profits held down by regulators trying to keep consumer electric bills low.

The lack of profit not only shrinks the amount of cash available for new construction but also hinders utilities' ability to service debt. For utilities the pre-tax interest coverage ratio, or the number of times earnings cover interest expense, has decreased from about 4.0 in the 1960's to levels approaching 2.0 in 1981. This has contributed to the downgrading of bond ratings of nearly 100 utilities and will ultimately result in higher interest charges which are paid by the customer. In addition, with a low coverage ratio many utilities are prohibited from issuing new bonds due to restrictions written into existing indentures. The low coverage ratio also indicates that a large part of utility earnings is used to pay fixed interest expenses. Most of the remainder of the earnings is used to pay taxes and dividends; there is little left to finance new construction and support RD&D. Another fact to consider is that a non-regulated industry can make and keep more profit and determine how to price and sell its product. Utility improvements in operations resulting in lower costs are returned to consumers through the rate structure. Allowed rates of return to utility investors are not commensurate with the level of risk associated with developing and demonstrating new technologies.

CONCLUSION

The electric utility industry has been responsive to national needs in formulating research, development and demonstration programs. This is evident in changes that have taken place in nuclear energy, environmental quality and conservation of energy. To continue these programs

will require the full support and cooperation of the Federal government.

Because of the benefits that can be realized by consumers and taxpayers through the early demonstration of new technologies, the Federal policy toward electric utility RD&D should be reviewed.

The electric utility industry can adjust its programs to assume a specific role that may no longer be seen as that of the Federal government. However, in adjusting to any new position, it is important that a transition period be established during which a coordinated change from government funded programs to industry funded programs can be planned. During this transition period, projects should be reviewed and areas identified where the Federal government has a role in supporting development of new technologies. It is very detrimental to national goals to terminate on-going programs for the sole objective of achieving a reduction in costs when the long-term consequences of not having those programs may be to increase future expenditures or result in a general decrease in national productivity.

We believe the joint participation of the Federal government and utility industry in past research programs has been productive, and that it can be productive in the future if properly coordinated. At PSE&G we are prepared to work with representatives of government to plan the future implementation of energy research, development and demonstration programs.

Mrs. BOUQUARD. Thank you very much for your fine statement, Mr. Lewis. We would like to welcome Mr. A. L. Bethel of Westinghouse Corp. as our next witness. You may proceed with your testimony as you see fit, Mr. Bethel.

STATEMENT OF A. L. BETHEL, EXECUTIVE VICE PRESIDENT, WESTINGHOUSE CORP., PITTSBURGH, PA.

Mr. BETHEL. Thank you, Madam Chairman, and good afternoon. I am A. L. Bethel, executive vice president of the Transmission and Distribution Group of the Westinghouse Corp. I have submitted a formal statement for the record, so I will merely summarize that statement in these comments.

My formal testimony addresses two questions: First, why is there a need for long-range research and development in such a mature industry as represented by the electric utilities in this country? And second, if there is a need for such long-range R. & D., how should it be provided?

As to the need for long-range R. & D. in the transmission and distribution of electric energy, I believe it is recognized today that the conservation of use of energy has as much probability for mitigating our energy problems as finding exotic new energy sources.

However, what is not as well recognized is the potential to conserve energy through more efficient transmission and distribution of electricity. Almost 10 percent of the total electricity generated by a utility is lost in the transmission and distribution of that energy using our present technology and equipment. The value of that energy, which is never utilized, was more than $5 billion in 1981. Fifty percent of these T. & D. losses are in the distribution transformers.

We now know of a new material called an amorphous metal, which has the potential of reducing these distribution transformer losses by 50 percent. For transformer purchases between 1980 and 1990, for load growth only, if losses were to be reduced 50 percent, utility systems losses would be reduced 100 billion kilowatt-hours less, or 165 million barrels of oil equivalent. In terms of operating costs, utilities would save $3 billion. Utility generation, addition, would be reduced by 3,000 megawatts, a savings of about $4 billion in capital investments.

These are reductions in cost to the electric utilities, and do not reflect the savings which would accure to all the users of electric energy, the customers of the utilities.

What does it take to make this come true? Almost $25 million of R. & D. has been spent on amorphous metal development since 1975. About $100 million more is needed before production quantitites will available, and the production problems associated with the new material will have been solved. Although the payoff potential is large, the R. & D. funds required are large also.

In the same vein, there are other high potential T. & D. projects in the long-range category. Increasing the transmission voltage level to 1,200 kilovolts offers the potential of 38 percent savings compared to 500 kilovolts, the predominant transmission voltage today.

Because of the cost of capital, and the present poor financial conditions of the U.S. electric utilities, meeting electrical growth demand is a major problem. Through the use of leading management, peak load demand can be reduced, resulting in reduced capital requirements and better use of more economical fuels. Within the past year, Carolina Power & Light and Duke Power separately announced projects to save $3 billion in construction funds through load management.

Another economic effort, through continuing our long-range R. & D. efforts in the transmission and distribution area, is the maintenance of the domestic electric equipment manufacturing industry, which is competitive throughout the world, in the face of most of our world competitors who enjoy protected home markets and Government-supported R. & D.

There are other important needs for long-range R. & D., including improving the reliability of our electric transmission and distribution systems, to prevent serious power disruptions like the Northeast blackout of 1965. Studies to determine health and environmental effects of higher voltage transmission are a must, if we are to reach these more cost-effective levels.

One solution to the environmental problem is compressed gas insulated transmission, or CGIT, as it is called in the trade, used in underground systems. DOE has spent over $7 million to date on 1,200 kilovolt CGIT, and if additional funding is not provided, this development will not continue.

Now I will address the subject of how long-range R. & D. should be funded. For the year of 1980, T. & D. research was funded by the electric utilities either directly or through EPRI, the equipment manufacturers and DOE. This amounted to EPRI funding and utility funding of about $30 million, about $100 million by the manufacturers, and DOE spent about $45 million, for a total of $175 million.

This R. & D. effort can be further differentiated on the basis of two factors. First is the degree of risk, and second is the length of time for commercial application. The utility programs for EPRI-funded interests are relatively near term, with emphasis on technology that can be commercialized in 1 to 5 years. On the other hand, DOE-funded R. & D. has been relatively long term, 5 to 15 years, and of greater uncertainty as to success.

The electrical equipment industry must necessarily concentrate on that R. & D. which can be quickly brought to the market, but to a limited extent will cost share with EPRI and DOE on those projects where it can be justified. Dr. George Mechlin, vice president R. & D. for Westinghouse, testified on July 15, 1981, to this Committee on Science and Technology at some length in regard to the funding of R. & D., and I refer you to his complete testimony. Let me remind you of his two main points:

Industry cannot justify long-term high-risk R. & D. because the payoff in terms of profit is so far in the future. As an example, with a prime rate of 20 percent, and a 30-percent probability of success for an R. & D. project, $100 of profit in the year 2000 would have to be realized for every dollar invested in R. & D. today. Obviously it would be difficult to compete for the investment dollar on this basis.

Second, R. & D. is only a small part of the overall cost of bringing a new technology to market. There is a considerably higher cost required in the transfer of the basic technology to the marketplace, and this, of course, is the role of industry to perform, and where its funds must necessarily be concentrated in our free enterprise system. The role of the private sector, both utility and manufacturer, in the area of funding R. & D., is therefore limited by the afford level that each enterprise can justify in the marketplace for investment funds, and will therefore be directed to short-range, low-risk projects.

On the other hand, the longer term, high-risk projects must be funded on a much broader basis by those who will share in the overall benefits of these high-return projects, and we are now talking about all of the consumers of electricity in this country, and their logical constituency is the Federal Government.

It should not be surprising to find that many other governments now assume this responsibility, and particularly those who are interested in exporting their products throughout the world. The role of the Japanese national government is well known in this regard, but other nations as well have recognized this need. France, for example, while protecting its home markets for domestic manufacturers, has met this need through research and testing laboratories operated by the government-owned utility EDF.

In summary, Westinghouse believes that it is essential for this country to continue long-range R. & D. in the field of transmission and distribution of electrical energy on the basis of maintaining the economic well-being of this country.

Second, that this long-range R. & D., having a realatively high risk, cannot be funded by either the electric utilities or the equipment-manufacturing industry due to the investment attraction process of our free enterprise system. Elimination of the DOE electrical energy system R. & D. funding would essentially eliminate all long-range R. & D. in the T. & D. area. This will ultimately have a major adverse effect on the electrical equipment manufacturers, and the final result will be a weakened industry and a loss of jobs for American workers.

Thank you.

[The prepared statement of Mr. Bethel follows:]

PREPARED STATEMENT OF A. L. BETHEL

Madame Chairman, and members of the Subcommittee on Energy Research and Production, good afternoon. I am A. L. Bethel, Executive Vice President of the Transmission and Distribution Group of the Power Systems Company of the Westinghouse Electric Corporation.

I appreciate the opportunity to testify on a subject which I consider to be very vital to the long-range economic well-being of this country. Of course, I represent my company's interest in research and development requirements pertaining to future electric energy systems, but I also believe that I reflect the views of the majority, if not all, of the other electric equipment manufacturers as well.

My testimony today will be divided into two areas:

1) Why is there a need for long-range research and development in such a mature industry as represented by the electric utilities in this country who are charged with the transmission and distribution of electric energy?

2) If there is a need for such long-range R&D, how should it be provided?

Where feasible, I will also give some examples, both from the past and hopefully for the future which will illustrate these points.

Concerning the need for long-range research and development in the area of transmission and distribution of electric energy, I believe it is well recognized today that the conservation of use of energy has a probability for solving our energy problems as great as finding exotic new energy sources. However, what is not as well recognized, and hopefully after today we will have a better understanding of, is the potential to conserve energy through more efficient transmission and distribution of electric energy thereby increasing our country's available supply of energy and even being able to reduce or forestall new investments in electric energy generation.

Let's look at a few figures.

Almost 10 percent of the total energy generated by a utility is lost in the transmission and distribution of that energy using our present technology and equipment that is in use today. The value of that energy which is lost and never utilized was more than $5 billion in 1981. Fifty percent of these T&D losses

are in the distribution transformers which are those which are located just outside your homes. We now know of a new material, amorphous metal, which has the potential of reducing these distribution transformer losses by 50 percent. What would that new development mean, if successful?

If the losses of transformers purchased in the 1980-1990 period (for load growth only) were reduced 50 percent, utilities would reduce system losses by 100 billion kWh, or 165 million barrels of oil equivalent. In terms of operating costs, utilities would save $3 billion over this 10 year period, assuming 3¢/kWh energy cost. Utility generation addition would also be reduced by 3000 MW, a savings of $4 billion in capital investment over 10 years.

In addition, if utilities replaced 5 percent of their existing transformer capacity each year with new units having 50 percent lower losses, generation requirements would be reduced an additional 3000 MW over the 10 year period, with a savings of $1.5 billion in operating costs and an additional $4 billion in capital investment.

The above are reductions in cost to the electric utilities and do not reflect the savings which will accrue to all the users of electric energy, the customers of the utilities. In the industrial area, the potential for productivity improvements will be increased through the availability of more economical energy.

What does it take to make this come true? Almost $25 million of R&D has been spent on amorphous metal development to date since 1975. It is estimated that $100 million more is needed before production quantities will be available and the production problems associated with the new material will have been solved. Though the payoff potential is large, the R&D funds required are large also. But this one example does illustrate the large potential for helping to solve this country's energy and economic problems through more efficient distribution of electric energy.

In the same vein, there are other high-potential T&D projects in the long-range category, such as increasing the transmission level to 1200 kV which offers the potential of 38 percent savings compared to 500 kV.

Because of the cost of capital and the present poor financial conditions of the U.S. electric utilities, meeting the electrical growth demand is a major problem. Through the use of load management, peak load demand can be reduced, resulting in reduced capital requirements and better use of more economical fuels.

On June 17, 1981, a Carolina Power and Light news release stated, "The new load management and conservation programs are designed to reduce the peak demand on the system 900,000 kW by 1995."

In the October 26, 1981 issue of Barron's, Duke Power Company quoted a change in growth from 5 percent to 3.8 percent through the use of load management and estimated that the cost of load management would only be one fifth the cost of the needed new capacity.

These two examples alone have the potential of saving $3 billion.

Aside from the tremendous economic savings possible in the operation of this country's energy systems, there is another formidable economic effect on a national scale through continuing our long-range R&D efforts in the transmission and distribution area, and that is the maintenance of a domestic electric equipment manufacturing industry which is competitive throughout the world and can compete effectively in those third world nations which do not have their own manufacturing capabilities. In addition, and unlike most of our world competitors who enjoy protected home markets, it will allow the industry to remain a vigorous and competitive supplier to our own markets, a factor especially important to the national security of this country.

The industry cannot maintain this position, however, without aggressive R&D programs, both short and long-range. It is particularly difficult to maintain our competitive edge when many of our world competitors receive large government supports in the area of protected home markets, export subsidies, and direct funding of R&D. In addition, there is collaboration between manufacturers which is not legal in this country.

In addition to helping maintain the economic well-being of our country through the effective utilization of our electric energy and maintaining our export capabilities, there are other important needs for long-range R&D such as improving the reliability of our electric transmission and distribution systems so as to prevent serious power disruptions such as the northeast blackout of 1965, and doing the necessary studies to prevent adverse health and environmental effects. One solution to the environmental problem is compressed gas insulated transmission (CGIT) underground systems. DOE has spent over $7 million to date on 1200 kV CGIT and if additional funding is not provided, this important development will not continue.

The need for long-range R&D in the T&D area has been established in the preceding paragraph, and we can address the area of how it should and must be funded.

You will note that I have been careful to specify the term "long-range" when referring to R&D and let me now define this term.

In order to do so, it is helpful to look at the entire area of R&D and if we take the year of 1980, T&D research was funded by the electric utilities (through EPRI), the electric equipment manufacturers, and DOE on the following basis:

EPRI	Industry	DOE	Total
$30 x 10^6	$100 x 10^6	$45 x 10^6	$175 x 10^6

This R&D effort can be further differentiated on the basis of two factors:

1) Degree of risk
2) Length of time for commercial application

The utility or EPRI funded interests are relatively near term (1-5 years) with emphasis on technology that can be commercialized in that time period and have a direct benefit to the utilities.

On the other hand, DOE funded R&D has been relatively long term (5-15 years) and of greater uncertainty as to success.

The electrical equipment industry, for reasons which I will cover, must necessarily concentrate on that R&D which can be quickly brought to the market, and to a limited extent will participate with EPRI and DOE on those projects where it can be warranted.

Dr. George F. Mechlin, Vice President of Research and Development for Westinghouse, testified on July 15, 1981 to your Committee on Science and Technology at some length in regard to the funding of R&D and I would refer you to his complete testimony. However, let me briefly, at this time, highlight his main points which were:

1) Industry, due to its necessity to compete for investment funds, cannot justify long-term, high risk R&D because the payoff in terms of profit is so far in the future. A typical example is, with a prime rate of 20% and a 30% probability of success for an R&D project, $100 of profit in the year 2000 would have to be realized for every dollar invested in R&D today. Obviously, it would be difficult to compete for the investment dollar on this basis.

2) R&D is only a small part of the overall cost of bringing a new technology to market. There is a considerably higher cost required in the transfer of the basic technology to the marketplace and this, of course, is the role of industry to perform and where its funds must necessarily be concentrated in our free enterprise system.

The role of private industry--both utility and manufacturer--in the area of funding R&D is therefore limited by the "afford level" that each enterprise can justify in the marketplace for investment funds and will therefore be directed to short-range low risk projects.

On the other hand, the longer term, high risk projects must be funded on a much broader basis by those who will share in the overall benefits of these high return projects. We are now talking about all of the consumers of energy in this country and their logical constituency is the federal government.

It should not be surprising to find that many other governments now assume this responsibility and particularly those who are interested in exporting their products throughout the world. The role of the Japanese national government is well known in this regard, but other nations as well have recognized this need. France, for example, while protecting its home markets for domestic manufacturers, has met this need through government research and testing laboratories.

I would be remiss not commenting on what I believe will be the effect of the new federal tax credit for research expenditures on the subject of corporate funding for long-range R&D in the T&D area. As you know, this 25 percent tax credit applies to the increase in R&D expenditures over the previous years which will generally be the average of the past three years. In addition, that which is considered to be R&D expense is severely limited and in the opinion of some, would only be about 40 percent of those expenses that industry considers to be R&D. For example, if a company had been having $50 million annual R&D expenditures and increased that by 10 percent or $5 million, the tax credit would be $500,000, a 10 to 1 ratio. The effect, therefore of financing new R&D expenditures will be small. In the main, however, it does not address the fundamental problem of how to attract funding for long-range R&D with long-term payoffs and high risks in a free enterprise economy where it is necessary to compete for investment funds.

In summary, Westinghouse believes that:

- It is absolutely essential for this country to continue long-range R&D in the field of transmission and distribution of electric energy on the basis of maintaining the economic well-being of this country.

- This long-range R&D having a relatively high risk cannot be funded by either the electric utilities or the equipment manufacturing industry due to the investment attraction process of our free enterprise system, but must be funded on a national basis by the federal government.

- The 25 percent reduction in T&D research represented by the proposed reduction in EES funding would essentially eliminate all long-range R&D in the T&D area. This will ultimately have a major adverse effect on the electric equipment manufacturers and the final result will be a weakened industry and a loss of jobs for American workers.

Mrs. BOUQUARD. Thank you very much, Mr. Bethel, for a very fine statement. In essence, our free enterprise system prohibits the sort of long-range funding it would take to accomplish long-term research. This is contrary to the administration's policy, saying "Let industy do it."

Mr. BETHEL. If we are going to get investors to invest in industry, we have got to continue to produce profits, and we produce profits by investing in the near term as opposed to the long term.

Mrs. BOUQUARD. Thank you very much.

I would like at this time, before we proceed with our next witness, to welcome my esteemed colleague, the ranking Republican member of this subcommittee, who is certainly a very valuable member of this committee, Mr. Lujan.

Mr. LUJAN. Thank you, Madam Chairman. I just want to apologize for being late. We got the Alaska natural gas pipeline waiver package on the floor and I was involved with that.

Mrs. BOUQUARD. We are happy that you have been able to come over here. I would like to say for the benefit of our chairman, Mr. Fuqua, that he is also tied up on the floor. I believe that he is sitting in the chair at this time.

Our next witness is Mr. Bob Pry. We are certainly happy to have you with us. Mr. Pry is from the Gould Corp. Please proceed with your testimony at this time.

STATEMENT OF ROBERT H. PRY, EXECUTIVE VICE PRESIDENT, RESEARCH AND DEVELOPMENT, GOULD, INC., ROLLING MEADOWS, ILL.

Mr. PRY. Thank you, Madam Chairman and members of the subcommittee. I want to thank you for the opportunity to appear before you today. My name is Robert Pry and I am executive vice president for research and development at Gould, Inc. Gould is a major manufacturer of electronic and electrical products, including a large variety of primary and secondary storage batteries.

Supporting our operating battery divisions is our laboratory for chemistry and materials, which provides R. & D. services to our company's operating divisions. The laboratory also serves to develop new electrochemical storage concepts for applications which may be many years from market commercialization.

During the past 10 years, our R. & D. has included efforts involving advanced lead acid automotive batteries, industrial batteries, submarine batteries, telephone standby batteries, advanced nickel/zinc and lithium metal sulfide EV batteries, zinc/bromine utility load leveling batteries, and a variety of special purpose batteries for advanced military as well as commercial applications. Many of those R. & D. efforts have been supported, in part, by funds from the U.S. Government, most especially the DOE and the DOD.

Continuing Government support of R. & D. programs, which could have a significant impact on the national welfare and security, is essential to assure a high probability of success for those funded programs. I would like to discuss that assertion in more detail at this time. An often raised question is one concerning the need for Government funding of R. & D. in the private sector. The question asks whether it is prudent policy to spend public moneys

to finance R. & D. which could lead ultimately to commercial products from which the recipient companies would derive significant profit. Although the question is reasonable and appears quite simple on its surface, the answer requires more than superficial analysis.

The issue at hand is not really whether Federal expenditures in the private sector could lead to private profit, but whether the private sector would actually undertake to spend its own resource on risky efforts whose successful outcome could substantially advance the public interest. Companies must always weight the matters of financial risk and reward for its investors when decisions are made concerning new product development. The Government must decide what actions in this area are required to provide for the national interest.

Even if the potential rewards of a development effort were quite large, a low probability of success or a very long-term payback period could be insurmountable obstacles to commencement or continuation of the effort. However, if the risk were reduced by a sharing of cost with the Government, or funding by the Government to the proof of feasibility study, then a decision to enter the development program could be positive.

Two examples in the area of battery R. & D. should serve to illuminate this point more clearly. In the area of automotive starting batteries, the important parameters for market success include cost, energy and power density, life, and maintenance requirements. Consider a case in which Gould decides to undetake development of an automotive battery with the same properties as are currently found on the market, except that the new battery would weigh, say, 10 percent less.

The advantages of such a battery would include lower shipping costs, lower material cost, and a very slight reduction in overall vehicle weight—that is, a slight fuel economy enhancement. Although these advantages would probably lead to a greater market share and more profit for Gould, their impact on national fuel savings and other public interest matters would be small.

Because the market for automotive batteries is well defined, the market impact of such an improved battery is easy to calculate and developmental success should lead to greater sales and profits in a relatively short time. Given these considerations, this is a case in which the company should consider spending its own resources and would not expect nor desire any Government support.

Now consider the case of development of an EV battery. A car fleet of only 10 percent EV could reduce current oil use by almost 0.75 million barrels per day. Such fuel savings would have to be considered as being in the public interest. However, the successful development of a long-life, low-cost, high-performance EV battery, risky though that development may be, will not by itself assure an EV market. Numerous external factors, such as oil cost, synthetic fuel availability, EV price, the availability of very efficient internal combustion engines, capital available to the auto industry, consumer acceptance of limited range vehicles, and electricity costs will all play a role in any future EV market. Even though potential sales and profits of EV batteries could be large, the financial risks are enormous.

And the time is long. Given the national interest implications, and the private sector risks involved, a prudent public policy would therefore dictate that the Government should assist in funding such battery R. & D. efforts.

I do not doubt the need to reevaluate Government spending priorities, but I do question the emphasis on cutting funds from programs where public expenditures are relatively small and the potential positive impact on the national interest is great.

The DOE storage program is very small compared to numerous other DOE programs, but the possible rewards are great indeed. Development of an acceptable EV battery could save hundreds of thousands of barrels of oil per day at a low cost to the taxpayer. President Carter's proposed 10-year, $88 billion synfuels program could have saved not much more oil, but at about 1,000 times the public costs of a successful EV battery development.

Battery R. & D. is important for other applications as well. Remember, electricity is the only form of energy that cannot be stored directly, efficiently and economically. Batteries that could perform that function could permit electric utilities to level their power demand, thereby reducing capital construction requirements, and helping to keep electricity price increases to reasonable levels, while also conserving the valuable fuels, natural gas, and distillate, which are used for peak power generation.

Improved electrical energy storage systems could lead to more rapid market acceptance of solar energy with all the associated environmental and oil conservation benefits.

Given the public importance of storage R. & D., and the relatively low public cost of those programs, I strongly recommend that the subcommittee endeavor to maintain continuity in Federal storage R. & D. funding.

I will answer any questions.

[The prepared statement of Dr. Pry follows:]

PREPARED STATEMENT OF DR. ROBERT H. PRY

MADAME CHAIRMAN AND MEMBERS OF THE SUBCOMMITTEE, I WANT TO THANK YOU FOR THE OPPORTUNITY TO APPEAR BEFORE YOU TODAY. MY NAME IS ROBERT PRY AND I AM EXECUTIVE VICE PRESIDENT FOR RESEARCH AND DEVELOPMENT AT GOULD INC. GOULD IS A MAJOR MANUFACTURER OF ELECTRONIC AND ELECTRICAL PRODUCTS, INCLUDING A LARGE VARIETY OF PRIMARY AND SECONDARY STORAGE BATTERIES. SUPPORTING OUR OPERATING BATTERY DIVISIONS IS OUR LABORATORY FOR CHEMISTRY AND MATERIALS, WHICH PROVIDES R & D SERVICES TO OUR COMPANY'S OPERATING DIVISIONS. THE LABORATORY ALSO SERVES TO DEVELOP NEW ELECTROCHEMICAL STORAGE CONCEPTS FOR APPLICATIONS WHICH MAY BE MANY YEARS FROM MARKET COMMERCIALIZATION.

DURING THE PAST TEN YEARS, OUR R & D HAS INCLUDED EFFORTS INVOLVING ADVANCED LEAD ACID AUTOMOTIVE BATTERIES, INDUSTRIAL BATTERIES, SUBMARINE BATTERIES, TELEPHONE STANDBY BATTERIES, ADVANCED NICKEL/ZINC AND LITHIUM METAL SULFIDE EV BATTERIES, ZINC/BROMINE UTILITY LOAD LEVELING BATTERIES, AND A VARIETY OF SPECIAL PURPOSE BATTERIES FOR ADVANCED MILITARY AS WELL AS COMMERCIAL APPLICATIONS. MANY OF THOSE R & D EFFORTS HAVE BEEN SUPPORTED, IN PART, BY FUNDS FROM THE U.S. GOVERNMENT, MOST ESPECIALLY THE DOE AND THE DOD.

CONTINUING GOVERNMENT SUPPORT OF R & D PROGRAMS, WHICH COULD HAVE A SIGNIFICANT IMPACT ON THE NATIONAL WELFARE AND SECURITY, IS ESSENTIAL TO ASSURE A HIGH PROBABILITY OF SUCCESS FOR THOSE PROGRAMS. I WOULD LIKE TO DISCUSS THAT ASSERTION IN MORE DETAIL AT THIS TIME. AN OFTEN RAISED QUESTION IS THAT CONCERNING THE NEED FOR GOVERNMENT FUNDING OF R & D IN THE PRIVATE SECTOR. THE QUESTION ASKS WHETHER IT IS PRUDENT POLICY TO SPEND PUBLIC MONIES TO FINANCE R & D WHICH COULD LEAD ULTIMATELY TO COMMERCIAL PRODUCTS FROM WHICH THE RECIPIENT COMPANIES WOULD DERIVE SIGNIFICANT PROFIT. ALTHOUGH THE QUESTION IS REASONABLE AND APPEARS QUITE SIMPLE ON ITS SURFACE, THE ANSWER REQUIRES MORE THAN SUPERFICIAL ANALYSIS.

THE ISSUE AT HAND IS NOT REALLY WHETHER FEDERAL EXPENDITURES IN THE PRIVATE SECTOR COULD LEAD TO PRIVATE PROFIT, BUT WHETHER THE PRIVATE SECTOR WOULD ACTUALLY UNDERTAKE TO SPEND ITS OWN RESOURCES ON RISKY EFFORTS WHOSE SUCCESSFUL OUTCOME COULD SUBSTANTIALLY ADVANCE THE PUBLIC INTEREST. COMPANIES MUST ALWAYS WEIGH THE MATTERS OF FINANCIAL RISK AND REWARD WHEN DECISIONS ARE MADE CONCERNING NEW PRODUCT DEVELOPMENT.

EVEN IF THE POTENTIAL REWARDS OF A DEVELOPMENT EFFORT WERE QUITE LARGE, A LOW PROBABILITY OF SUCCESS OR A VERY LONG TERM PAYBACK PERIOD COULD BE INSURMOUNTABLE OBSTACLES TO COMMENCEMENT OR CONTINUATION OF THE EFFORT. HOWEVER, IF THE RISK WERE REDUCED BY A SHARING OF COST WITH THE GOVERNMENT, THEN A DECISION TO ENTER THE DEVELOPMENT PROGRAM COULD BE POSITIVE.

TWO EXAMPLES IN THE AREA OF BATTERY R & D SHOULD SERVE TO ILLUMINATE THIS POINT MORE CLEARLY. IN THE AREA OF AUTOMOTIVE STARTING BATTERIES, THE IMPORTANT PARAMETERS FOR MARKET SUCCESS INCLUDE COST, ENERGY AND POWER DENSITY, LIFE, AND MAINTENANCE REQUIREMENTS. CONSIDER A CASE IN WHICH GOULD DECIDES TO UNDERTAKE DEVELOPMENT OF AN AUTOMOTIVE BATTERY WITH THE SAME PROPERTIES AS ARE CURRENTLY FOUND ON THE MARKET, EXCEPT THAT THE NEW BATTERY WOULD WEIGH 10 PERCENT LESS. THE ADVANTAGES OF SUCH A BATTERY WOULD INCLUDE LOWER SHIPPING COSTS, LOWER MATERIAL COST, AND A VERY SLIGHT REDUCTION IN OVERALL VEHICLE WEIGHT (I.E., A SLIGHT FUEL ECONOMY ENHANCEMENT). ALTHOUGH THESE ADVANTAGES WOULD PROBABLY LEAD TO A GREATER MARKET SHARE AND MORE PROFIT FOR GOULD, THEIR IMPACT ON NATIONAL FUEL SAVINGS AND OTHER PUBLIC INTEREST MATTERS WOULD BE SMALL. BECAUSE THE MARKET FOR AUTOMOTIVE BATTERIES IS WELL DEFINED, THE MARKET IMPACT OF SUCH AN IMPROVED BATTERY IS EASY TO CALCULATE AND DEVELOPMENTAL SUCCESS SHOULD LEAD TO GREATER SALES AND PROFITS IN A RELATIVELY SHORT TIME. GIVEN THESE CONSIDERATIONS, THIS IS A CASE IN WHICH THE COMPANY SHOULD CONSIDER SPENDING ITS OWN RESOURCES AND WOULD NOT EXPECT ANY GOVERNMENT SUPPORT.

NOW CONSIDER THE CASE OF DEVELOPMENT OF AN EV BATTERY. A CAR FLEET OF ONLY 10 PERCENT EV COULD REDUCE URRENT OIL USE BY ALMOST .75 MILLION BARRELS PER DAY. SUCH FUEL SAVINGS WOULD HAVE TO BE CONSIDERED AS BEING IN THE PUBLIC INTEREST. HOWEVER, THE SUCCESSFUL DEVELOPMENT OF A LONG-LIFE, LOW COST, HIGH PERFORMANCE EV BATTERY WILL NOT BY ITSELF ASSURE AN EV MARKET.

NUMEROUS EXTERNAL FACTORS, SUCH AS OIL COST, SYNTHETIC FUEL AVAILABILITY, EV PRICE, THE AVAILABILITY OF VERY EFFICIENT INTERNAL COMBUSTION ENGINES, CAPITAL AVAILABLE TO THE AUTO INDUSTRY, CONSUMER ACCEPTANCE OF LIMITED RANGE VEHICLES, AND ELECTRICITY COSTS WILL ALL PLAY A ROLE IN ANY FUTURE EV MARKET. EVEN THOUGH POTENTIAL SALES AND PROFITS OF EV BATTERIES COULD BE LARGE, THE FINANCIAL RISKS ARE ENORMOUS. GIVEN THE NATIONAL INTEREST IMPLICATIONS, AND THE PRIVATE SECTOR RISKS INVOLVED, A PRUDENT PUBLIC POLICY WOULD THEREFORE DICTATE THAT THE GOVERNMENT SHOULD ASSIST IN FUNDING SUCH BATTERY R & D EFFORTS.

I DO NOT DOUBT THE NEED TO RE-EVALUATE GOVERNMENT SPENDING PRIORITIES, BUT I DO QUESTION THE EMPHASIS ON CUTTING FUNDS FROM PROGRAMS WHERE PUBLIC EXPENDITURES ARE RELATIVELY SMALL AND THE POTENTIAL POSITIVE IMPACT ON THE NATIONAL INTEREST IS GREAT.

THE DOE STORAGE PROGRAM IS VERY SMALL COMPARED TO NUMEROUS OTHER DOE PROGRAMS, BUT THE POSSIBLE REWARDS ARE GREAT INDEED. DEVELOPMENT OF AN ACCEPTABLE EV BATTERY COULD SAVE HUNDREDS OF THOUSANDS OF BARRELS OF OIL PER DAY AT A LOW COST TO THE TAXPAYER. PRESIDENT CARTER'S PROPOSED 10-YEAR, $88 BILLION SYNFUELS PROGRAM COULD HAVE SAVED NOT MUCH MORE OIL, BUT AT ABOUT 1,000 TIMES THE PUBLIC COST OF A SUCCESSFUL EV BATTERY DEVELOPMENT REPORT.

BATTERY R & D IS IMPORTANT FOR OTHER APPLICATIONS AS WELL. BATTERIES COULD PERMIT ELECTRIC UTILITIES TO LEVEL THEIR POWER DEMAND, THEREBY REDUCING CAPITAL CONSTRUCTION REQUIREMENTS, AND HELPING TO KEEP ELECTRICITY PRICE INCREASES TO REASONABLE LEVELS, WHILE ALSO CONSERVING THE VALUABLE FUELS, NATURAL GAS AND DISTILLATE, WHICH ARE USED FOR PEAK POWER GENERATION.

IMPROVED ELECTRICAL ENERGY STORAGE SYSTEMS COULD LEAD TO MORE RAPID MARKET ACCEPTANCE OF SOLAR ENERGY WITH ALL THE ASSOCIATED ENVIRONMENTAL AND OIL CONSERVATION BENEFITS.

GIVEN THE PUBLIC IMPORTANCE OF STORAGE R & D, AND THE RELATIVELY LOW PUBLIC COST OF THOSE PROGRAMS, I STRONGLY RECOMMEND THAT THE SUBCOMMITTEE ENDEAVOR TO MAINTAIN CONTINUITY IN FEDERAL STORAGE R & D FUNDING.

I AM NOW PREPARED TO ANSWER ANY QUESTIONS WHICH THE SUBCOMMITTEE MEMBERS MAY HAVE PERTAINING TO THIS IMPORTANT SUBJECT.

Mrs. BOUQUARD. Thank you very much. I appreciate your testimony.

Last but not least, we welcome Dr. Jon Pangborn. Please proceed with your testimony.

STATEMENT OF JON B. PANGBORN, VICE PRESIDENT, ENGINEERING RESEARCH, INSTITUTE OF GAS TECHNOLOGY, CHICAGO, ILL.

Mr. PANGBORN. Thank you, Madam Chairman and members of the subcommittee. I am Dr. Jon B. Pangborn, vice president of engineering research at the Institute of Gas Technology in Chicago, Ill. IGT, a not-for-profit research and educational organization, has been performing energy research for gas, petroleum, utility industries, industrial trade associations, and various governmental agencies since 1941.

I have been involved in energy research dealing with production, storage and delivery of heat and fuels since 1941.

My testimony will show that energy storage will continue to increase in importance and that fundamental and applied research is needed to develop the innovative technologies that will be required. For the purposes of this hearing I will summarize my written testimony and I will present some research funding needs for thermal energy and hydrogen storage.

In the United States, relatively large amounts of energy are stored as fuels in their natural or refined chemical forms, and economic delivery to the consumer is very dependent upon this ready reserve of fuel. My written testimony shows that 15 percent of our annual consumption of natural gas, crude oil, and refined products and 30 percent of our annual coal consumption are normally kept in storage.

In order to meet the seasonal heating and cooling requirements in the United States, 18 times more energy is needed in the winter than in the summer. In the Northeastern United States this factor increases to 90 times. The need for energy storage in order to meet large changes in energy demand is evident.

The large seasonal changes in energy demand are evident.

As the prices for fossil fuels increase, the economics of renewable energy sources become more attractive.

One thermochemical method of thermal energy storage [TES] for onsite commerical or industrial usage of solar energy is the use of melted salt or salt mixtures. Conventional molten-salt storage systems require the use of costly heat exchanger tubes.

By proper selection of salt and ceramic materials to achieve chemical compatibility, this concept may be developed for a broad range of solar, industrial, utility, and even residential applications spanning the significant temperature range of 200° C to 1,200° C. In principle, this advanced technology may be implemented with different families of salts or salt mixtures with compatible low-cost ceramic materials and with numerous practical heat exchange fluids.

Many rather basic and relatively long-term research functions in thermal energy storage need attention and Government funding

before industry involvement is practical. These research functions and their costs and expected durations are as follows:

Measurement of physical and chemical properties of potential media materials.

This experimental work could involve 25 different molten-salt systems with $100,000 per year required for each system. The duration of each study would be 3 years and the total funding requirement would be $7.5 million.

Optimization of media thermal and physical behaviors within expected operating conditions.

This study would entail the optimization of about 15 molten salt systems and would require $250,000 for each study. The time required would be 2 years, and the total cost would be $3.75 million.

Media selection/development to fit application temperatures and operating requirements.

To carry this out, the heat schedule requirements for the different thermal processes would have to be investigated with 10 specific industrial plants. Each process study would require $100,000 and would take 1 year. The matching of 15 thermal energy storage systems and the selection of 10 candidates would cost $750,000, and in-depth study of the 10 selected systems would require $4 million. With a 3-year total duration, this selection and application study would cost about $5.75 million.

Materials compatibility studies addressing media, containment, working fluids and auxiliary components.

These experimental and analytical studies would involve 10 candidate systems at a cost of $400,000 over 2 years. The total funding requirement would be $4 million.

The fifth area of thermal energy storage which deserves support is modeling of the applications.

Mathematical modeling of heat transfer performance and optimum integration into the heat-source/heat-use sequences.

Modeling of the 10 selected systems would develop and compare expected performance with actual inplant experiments. The inplant experiments would be industry funded. The modeling costs borne by the Government would total $2 million and would be expected to require 2 years.

The composite salt and ceramic phase-change concept described above is potentially usable to hundreds of companies and thousands of plants in the brick, ceramic and refractory industries alone, and to other industries that rely on high-temperature processes as well. We do not know which salts and ceramics will mate with which applications because the operating parameters are yet to be researched. We cannot expect an individual company or a dispersed group of companies to support this R. & D. on their own. The financial requirements are great and the risk higher than that which a small business can afford.

Now I will address the topic of energy storage as hydrogen. Hydrogen can be a storage techique for electric power or a convenient medium for the distribution of solar, fossil, and nuclear energy. While hydrogen R. & D. must strive to reduce production costs, emphasis is also needed to research and develop hydrogen storage, distribution, and utilization.

Premium fuels, such as oil, are being used to meet peaking electrical demand requirements. It is not economical or practical to build nuclear or large coal-fired plants for turndown operation and peak supply. To avoid further use and dependence on premium fuels in the future, there is a need for a competitive and practical means of large storage of electricity. Hydrogen can meet this need.

In general, hydrogen fuel—for storage and use—is too long term, and involves too much advanced technology or extremes in operating conditions to be of interest now to the gas industry, petroleum industry, or electric utilities.

The hydrogen research needs include the following:

1. Experimental work on thermochemical and photochemical conversion of solar energy to hydrogen.

In hydrogen storage this is the most important research function needing Government support. A long-term dedicated program is required to address multiple techniques with each being a high-risk, high-reward prospect. At $2 million per year, the total 15-year effort would require $30 million.

2. Design and carryout underground hydrogen storage experiments.

In this major and necessary endeavor, the Government would fund a $2-million design study for the development of an experimental field facility. The actual development and testing of this facility would involve industry with cofunding. The total effort would require $50 million and 5 years to complete.

3. Experimental design and development of an electrolyzer hydride storage-electric generator system for peak load needs.

A practical round-trip electricity-to-hydrogen-to-electricity system would be of great use to the utility industry. However, fundamental investigations of electrodes, electrlytes, catalysts and separation materials as well as the hydrogen storage medium need Government support. This program would require $3 million per year for 10 years.

4. Long-term hydrogen exposure and compatibility experiments in gas delivery equipment.

With industry contributing much of the equipment and Government supporting the establishment and operation of an experimental facility, the questions about long-term hydrogen exposure on gas delivery equipment would finally be answered. This work is a prerequisite to any gas company or combination gas and electric company testing hydrogen in their own delivery system. The first year would cost $3 million to establish the facility. The 14 succeeding years would each cost $5 million for a total 15-year, $10-million program.

5. Fundamental studies of catalytic, flameless, combustion of hydrogen.

An entirely new, safe and pollution-free method of combusting a fuel could be attained by low-temperature, flameless catalytic burning of hydrogen. Very preliminary laboratory experiments have verified this promise; however, catalysts, operating conditions and burner configurations remain to be explored. This fundamental work deserves Government support at a level of $2 million per year for 5 years. The result could be a revolutionary new way of utilizing a fuel gas in residential, commercial, and industrial markets.

In summary, thermal energy storage can be a practical means for storing and retrieving heat at constant, high temperatures. Solid molten-salt phase-change systems require significant laboratory-scale study. For many specific salt and ceramic systems we lack the thermochemical and physical data needed to propose and select applications. The high-temperature process heat industries are composed of many relatively small companies with differing requirements for energy storage. At this time it is premature to expect research funding from this industry. Government funding in the interim is essential.

Storing solar or nuclear power as hydrogen requires further thermochemical and photochemical work at laboratory scale and electrolyzer development in order to increase efficiencies and reduce costs.

The energy industry does view hydrogen as a good option of the far term, and hydrogen needs long-term dedicated research with continued Government support to be such an option.

Thank you for the invitation to testify before you and for your kind attention.

[The prepared statement of Mr. Pangborn follows:]

PREPARED STATEMENT OF DR. JON B. PANGBORN

RESEARCH NEEDS IN ENERGY STORAGE

Background and Introduction

I am Dr. Jon B. Pangborn, Vice President of Engineering Research at the Institute of Gas Technology in Chicago, Illinois. IGT has been performing energy research for gas, petroleum, utility industries, industrial trade associations and various governmental agencies since 1941. I have been directly involved in energy research dealing with production, storage and delivery of heat and fuels for 10 years. My testimony will show that energy storage will continue to increase in importance and that fundamental and applied research is needed to develop the innovative technology that will be required. For purposes of this hearing I will focus on thermal energy and hydrogen storage.

Need for Energy Storage

Energy storage is categorized by time frame and form. Energy is stored for use in amounts corresponding to hourly or daily needs, weekly needs or seasonal needs. Gasoline in an automobile tank is an example of daily storage while underground storage of natural gas in a developed aquifer or depleted gas field is an example of seasonal storage. Usually, smaller amounts of energy in the forms of fuel or heat are stored near the place of usage; larger stocks are kept near the production sites or along delivery or transmission routes.

In the United States, relatively large amounts of energy are stored as fuels in their natural or refined chemical forms,

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and economic delivery to the consumer is very dependent upon this ready reserve of fuel. The table below illustrates the magnitude of fossil-based seasonal and other storage upon which our energy economy currently depends.

Stored Energy Form	Amount in Quads (10^{15}Btu)	% of Annual Use
Natural Gas (underground)	3.0 (deliverable)	15
Coal (washed & piled)	4.5	30
Petroleum (crude & refined products)	5.0	15

In order to meet the seasonal heating and cooling requirement in the U.S., 18 times more energy is needed in the winter than in the summer. In the northeastern U.S. this factor increases to 90 times. The need for energy storage to meet large changes in energy demand is evident. Industrial and commercial energy usage for manufacturing, chemical and metallurgical processes and consumer services have more constant seasonal energy demands. However, daily energy needs fluctuate significantly.

On-site industrial process heat recuperation and storage has long been in practice; and in the future it will be more necessary because of increasing energy prices. New methods of on-site heat transfer and storage need to be developed for many thermochemical industries including glass, ceramic, cement, brick-making, iron and steel production, petroleum refining and petrochemical production.

Future Alternative Energy Forms and Storage

The U.S. has experienced increasing prices for petroleum and natural gas with the primary driving forces for these increases being: (a)continual depletion of domestic reserves and (b)price control by foreign suppliers.

The accompanying chart (attachment no. 1) taken from the August 3, 1981 "Energy Topics" of IGT illustrates the price trends for the period 1950-1980.

As the prices for fossil fuels increase, the economics of renewable energy sources become more attractive. Solar energy is a prime renewable energy source which the U.S. has been developing in both the public and private sectors. For practical uses other than local space and water heating, solar energy requires an economic conversion method to a fuel that must have a high-volume storage capability. This will require conversion to a chemical fuel form. Candidate chemicals include alcohols, ammonia, hydrogen, refined metals that are battery electrodes and perhaps even methane, the principal constituant of natural gas. Thus, large-scale storage of solar energy will require development of chemical conversion processes which may be one or a combination of thermochemical or photovoltaic processes.

Thermal Energy Storage

One thermochemical method of thermal energy storage (TES) for on-site commercial or industrial usage of solar energy is the use of salt or salt mixtures. Conventional molten salt storage systems require the use of costly heat exchanger tubes.

If innovative combinations of salt and ceramic materials can continue to be successfully developed, the need for heat exchange tubes would be eliminated. Not only would the cost of salt storage be greatly reduced, but heat transfer rates and system efficiency would also be enhanced. This enhancement is possible because of the ability of combination salt/ceramic materials to operate in direct contact with compatible gas and transfer fluids.

By proper selection of salt and ceramic materials to achieve chemical compatability, concepts may be developed for a broad range of solar, industrial, utility and even residential applications spanning the significant temperature range of 200°C to 1200°C. In principle, this advanced technology may be implemented with different families of salts or salt mixtures (carbonates, nitrates, hydroxides, chlorides or fluorides) with compatible low-cost ceramic materials and with numerous practical heat exchange fluids (air, combustion and process gasses, inert gasses and organic oils). It may also be possible to extend the concept to other composite materials (e.g. molten metal/ceramic, molten metal/solid metal, organics/ceramic, etc.) for future advanced applications.

Potential users that will benefit from these and other advanced heat storage concepts include many small industrial companies (ceramic tile, brick, metal heat treating, drying and curing operations) and residential/commercial users not having the financial resources required to develop high risk/high benefit TES technologies.

In the United States the brick, ceramic, clay products and refractory industries consume approximately 1.5 quad (1.5 X 10^{15}Btu) annually and consist of roughly 600 companies nationwide. An energy conservation system incorporating advanced TES media could be applied to plants using periodic kilns. The approximately 3000 periodic kilns in the U.S. use 0.4 X 10^{15}Btu annually. It is estimated that the energy savings resulting from an advanced TES media system in these periodic kiln plants would be approximately 0.25 X 10^{15} Btu per year.

A broad-based generic R&D program is thus required to address the many applications and operating requirements as well as the many possible TES media/system configurations identified or thought to be possible. After sufficient research and technology development, industrial trade associations, TES user groups with comparable requirements, and potential TES system manufacturers could be involved. Once the applications and system parameters are understood, they could fund process development technology transfer, demonstration and commercialization of most promising concepts for their industries or end-use applications. However, many rather basic and perhaps long-term TES research functions need attention and funding before industry involvement is practical or expected. These include the following:

- Measurement of physical and chemical properties of potential media materials.

- Optimization of media thermal and physical behaviors within expected operating conditions.
- Media selection/development to fit application temperatures and operating requirements.
- Materials compatibility studies addressing media, containment, working fluids and auxiliary components.
- Mathematical modeling of heat transfer performances and optimum integration into heat-source/heat-use sequence.

In thermal energy storage (TES), many basic concepts need experimental research in the laboratory and many different materials need measuring and evaluation. The concept of storing heat in inorganic salts which change from solid phase to liquid at high temperature while contained in a ceramic or porous material is most promising as a method for delivering or giving back heat at a constant, high temperature.

The composite salt and ceramic phase-change concept described above, is potentially usable to hundreds of companies (thousands of plants) in the brick, ceramic and refractory industries alone, and to other industries that rely on high-temperature processes (metal smelting and refining, cement, etc.) as well. We do not know which salts and ceramics will mate with which applications because the operating parameters are yet to be researched. We cannot expect an individual company or a dispersed group of companies to support this R&D on their own. The financial requirements are great and the risk

higher than that which a small business can afford. Government support at this stage is imperative. Once the thermochemical behavior of the materials is tested and the full potential of applications are known industry would be better able to establish financing.

Hydrogen Storage

Hydrogen can be a storage technique for electric power or a convenient medium for the distribution of solar, fossil and nuclear energy. While hydrogen R&D must strive to reduce production costs, emphasis is also needed to research and develop hydrogen storage, distribution and utilization.

Premium fuels, such as oil, are being used to meet peaking electrical demand requirements. It is not economical or practical to build nuclear or large coal plants for turn-down operation and peak supply. To avoid further use and dependence on premium fuels in the future, there is a need for a competitive and practical means of storing electricity. Hydrogen can meet this need. It can be produced with base line (fossil, nuclear and solar) power stations, stored, and then later utilized in both conventional (gas turbine) and advanced (fuel cell) electric power peaking generation equipment. Unlike batteries and mechanical storage devices such as flywheels, hydrogen can be stored for long durations without degradation of energy quality. In addition, the capital investment for storage equipment is much less for hydrogen than that required for alternative methods.

Significant advances have been made at the hardware stage for electrolytic production of hydrogen from water. Considerable progress has been made at the laboratory level in developing "thermochemical" processes to split water using heat rather than electricity. Two thermochemical processes have been operated continuously at laboratory scale to split water into hydrogen and oxygen; many others have been demonstrated to operate on a batch scale, with the promise of achieving overall heat-to-hydrogen fuel efficiencies of 40% to 50%. It is too early to accurately forecast the costs of thermochemical hydrogen production. Encouraging results have been obtained by a number of researchers on producing hydrogen from water by using direct sunlight, and by using processes resembling fermentation. Early results from these fundamental studies show that there are other, potentially simpler paths for the production of hydrogen, but they do not yet meet cost or performance criteria.

In tests limited to a 6 month duration, hydrogen gas has been shown to be compatible with natural gas distribution equipment, though some meters would have to be replaced with larger sizes. There are some unanswered questions as to the safety of welds if high-pressure gas-transmission lines were operated on hydrogen, but operation in a safe mode does appear feasible. The cost of long-distance energy transmission by hydrogen appears to be at least one-third to one-tenth that of electricity. It appears quite possible to store vast quantities of energy as hydrogen in underground formations, although the cost will be three or

four times that of storing natural gas. Hydrogen - natural gas blends with hydrogen up to about 15% by volume have been found to be interchangeable with natural gas, but with blends above 15% hydrogen, appliance burners will have to be replaced or adjusted. So far, no insurmountable technical obstacles to using hydrogen as a replacement for natural gas have been found.

In general, hydrogen fuel (for storage and use) is too long-term, and involves too much advanced technology or extremes in operating conditions to be of interest now to the gas industry, petroleum industry or electric utility.

The gas industry has a long term interest in hydrogen. However, hydrogen can only displace natural gas as a fuel if its price is lower. Eventually this will be the case. The gas industry now believes there is enough "methane" from natural, unconventional and synthetic sources to supply its customers for at least a decade. Therefore, no immediate incentive exists to develop significant hydrogen production at lower prices.

As long as adequate supplies of oil are available to produce hydrogen for refining processes, and near-term alternative methods are viewed as uneconomic, the oil industry has no incentive to pursue alternative methods for hydrogen production.

The electric industry is interested in hydrogen as an energy storage technique. However, current and future financial commitments by the electric industry limit available risk capital for investment in hydrogen storage research. In addition, the electric industry views hydrogen as a competitive technology to

conventional methods of transmitting electric energy and consider hydrogen in this context as being in the gas industry's domain.

Sponsorship of Energy Storage Research

Research of a basic and long-term nature needs government support to bring energy conversion and storage concepts or methods to the stage where industries or individual companies can see specific applications to their operations within a near-term time frame. Thus, research sponsorship depends not only on the size of the monetary investment and risk factors, but also upon the timing of practical implementation.

In our economy today, many measures of money rates exceed 15%, the prime lending rate is an example. Most companies must consider investments with payback periods of 4 to 6 years or less and the return on investment should be 15%. Hence, funding of energy storage research is difficult to obtain from the energy industry. Examples of two sponsors (not-for-profit) who do fund relatively small programs in or related to fuel storage are the Pipeline Research Committee of the American Gas Association (industry supported by gas company contributions) and the Gas Research Institute (supported by a surcharge on delivered gas). The A.G.A. is supporting at IGT a study of underground storage of different fuel gases and their on-site mixing and blending rates. The G.R.I. , in their Basic Research Group, is supporting at IGT, research on photocatalytic methods for converting solar energy and water to hydrogen. Much work needs to

to be done. Research needs include the following long-term programs:

- Experimental work on thermochemical and photochemical conversion of solar energy to hydrogen.
- Design and carry-out underground hydrogen storage experiments.
- Experimental design and development of an electrolyzer-hydride storage-electric generator system for peak load needs.
- Long-term hydrogen exposure and compatability experiments in gas delivery equipment.
- Fundamental studies of catalytic (flameless) combustion of hydrogen.

Conclusions

In thermal energy storage, a practical means for storing and retrieving heat at constant, high temperatures needs laboratory development and individual systems need proof-of-concept. Solid-molten salt phase-change systems require laboratory study. For many specific salt and ceramic systems we lack the thermochemical and physical data needed to propose and select applications. The high-temperature process heat industries are composed of many relatively small companies with differing requirements for energy storage. Research funding at this time, is premature to expect from this industry. Government funding in the interim is essential.

Storing solar or nuclear power as hydrogen requires further thermo-and photochemical work at laboratory scale and electrolyzer development in order to increase efficiencies and reduce

costs. The energy industry does view hydrogen as a good option for the far-term, and hydrogen needs long-term dedicated research with continued government support to be such an option.

Thank you for the invitation to testify before you and for your kind attention.

Attachment No. 1

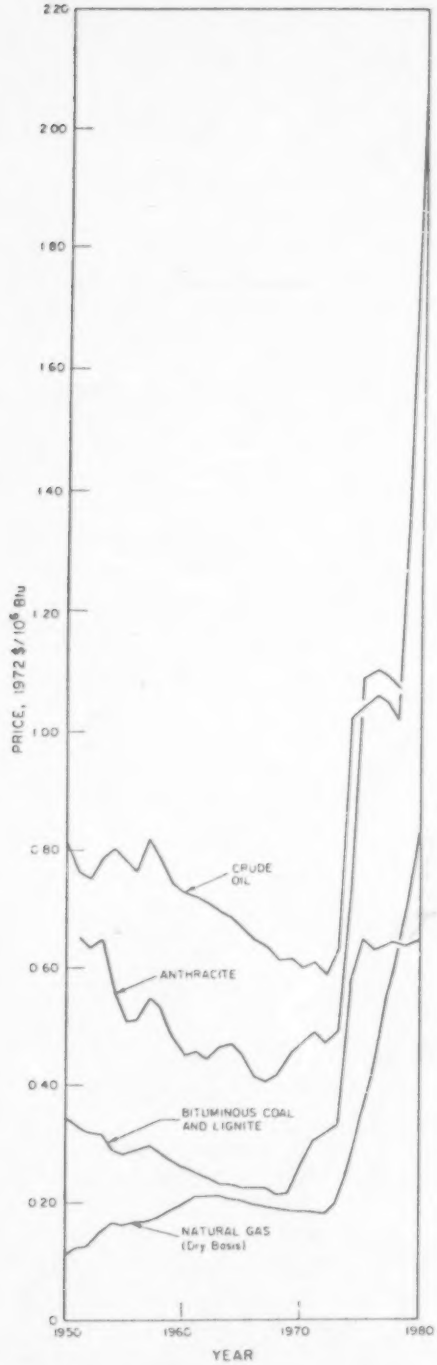

Figure 6. REAL PRICE TRENDS OF DOMESTICALLY PRODUCED FOSSIL FUELS
(Prices as close as possible to point of production)
Data source: U.S. Bureau of Mines and DOE

Mrs. BOUQUARD. I want to thank all of you for your outstanding testimony today. It was not only presented well but in content it was very factual and very pertinent. I am going to allow myself about 10 minutes and will give the same courtesy to Mr. Lujan. Dr. Schneider, in your testimony you spoke about long-term and short-term investments. What is the typical timespan, would you say, to develop a concept to the point that a product or a system is really ready for the marketplace?

Mr. SCHNEIDER. If we restrict ourselves to new energy technology developments, rather than things like hula hoops, the history tends to indicate that technology development takes 20 and 30 years from the time a concept's scientific feasibility is established, to the time that a truly mature market exists. For example, you can look at the computer industry, which has been mature now for the last 10 years, but the basic development efforts came about in the 1940's. You can look at gas turbines, the first gas turbine was operated in 1938, but the significant sales of gas turbines in the United States didn't occur until the mid-1960's, and that is a relatively simple technology compared to some of the systems that we have talked about today.

At the same time there are near-term improvements that are really product refinements that can be put in place rather quickly, or the adaption of new types of technology that have been mature in other areas to new applications, and that too can be done rather quickly. For example, water-jet cutting equipment used for cutting up a street rather than airhammers—you can take this application to market within a few years.

So the answer is really, it depends on the particular situation. The high-technology areas tend to take a long time. Application of things we know about today, which are really product improvements or applying existing concepts in new ways usually can be done in a few years.

Mrs. BOUQUARD. Thank you very much.

Mr. Lewis, we spoke earlier about the impact of trying to hold down the cost of utility bills to consumers, and this certainly prohibits a lot of investing by utility companies. What impact can energy storage or electric systems R. & D. have on holding down the cost of power to the consumers? How does this fit in?

Mr. LEWIS. At the present time the means of supplying peakload requirements by electric utility systems is generally through the use of gas turbines which have a low capital investment, but a generally high fuel cost. By going to energy storage, it would be possible to use more efficient systems that would store electricity produced by nuclear and coal generating facilities, and use this at time of peakloads more efficiently than combustion turbines. There will also be an attendant saving in fuel oil use.

Mrs. BOUQUARD. What is the burn rate on that gas turbine?

Mr. LEWIS. We have a number of gas turbines installed on the public service system. Our largest ones have a rating of approximately 200 megawatts, and they would burn approximately 21,000 gallons of oil an hour. As a general rule of thumb, there is approximately 100 gallons of oil per hour burned per megawatt generated by a combustion turbine. This is eqivalent to about 2½ barrels per hour, per megawatt.

Mrs. BOUQUARD. Thank you.

Mr. Bethel, how do antitrust laws impact R. & D., and how do they restrict our companies from competing against our foreign competitors?

Mr. BETHEL. In terms of competing in the marketplace, I don't find that our antitrust laws are any impediment. If large projects are required, we are perfectly at liberty to form consortia to carry through a specific project, so there is no problem from that point of view.

I think there is a financial advantage that many of our foreign competitors enjoy, and I will take Japan as an example, where the Japanese electrical manufacturers are brought together by MITI to carry out specific joint research and development programs for which they get funding from the Japanese Government.

Mrs. BOUQUARD. Would you explain the function of MITI?

Mr. BETHEL. MITI is the Ministry of International Trade and Industry in Japan. They are sort of the liaison link, if you will, between the Japanese Government and Japanese industry. Working with the Japanese governmental agencies broadly, they develop a whole set of long-range national goals, and then MITI will take specific pieces of those goals and decide how they are to be accomplished, and they might draw two or three electrical manufacturers together, and plan a specific research and development program to achieve certain things in certain frames, and provide funding. Part of it comes from the manufacturers, but part of it comes from the Government, given to them through MITI.

Now, the impact is that by being able to share that development information, which has been jointly achieved and partly funded, their cost structure is significantly lower than ours, where each of our companies does this on their own, with EPRI help or with DOE help certainly. But the sharing of information and the Government funding gives Japanese companies a distinct cost advantage and therefore a price advantage in international competition.

I am not advocating that we change our laws to do that, but there is a reverse advantage that they get.

Mrs. BOUQUARD. Thank you very much.

Dr. Pry, what R. & D. expenditures has Gould made in new battery technology in the last 10 years?

Mr. PRY. Let me address that question relative to all of its technology in batteries and its source. We have received over about the last decade approximately $12 million from DOE and associated agencies relative to battery development. To put that in context, we spent prior to the time that DOE really got involved in electric car development, about $4.5 million in a demonstration project with the post office in which we sold about 350 electrified Jeeps to them, and the subsequent maintenance and experiments with those vehicles over time until this last year involved an expenditure of Gould's funds—not the post office funds but Gould's funds—of about $4.5 million.

In addition to that, we have spent to date about $5 million on nickel-zinc research and development of Gould funds, about the same amount as DOE. About $1 million on zinc chlorine. We decided to give up that effort about 1975, an equivalent amount on zinc/bromine, both of which are load-leveling-type storage batteries, and

to date about $1.5 million on lithium metal sulfide. That totals something on the order of $13 million of Gould's money compared to about $12 million DOE.

Now, in addition to that, of course, relative to the kind of technologies I talked about in lead acid batteries, we have over the last 10 years spent perhaps $25 to $30 million over and above what I have stated earlier, so that the primary research and development funds for product development in Gould have been company funds, both for the near and medium term.

I would like, if I can, to expand on your question for just a moment, to reflect on an issue that is often brought up relative to the use of Government funds, and the reluctance of private industry to stop an experiment utilizing those funds when it is unsuccessful.

I would like to point out in that regard that Gould last year, with respect to the nickel/zinc battery—which incidentally was discarded by Edison around 1900—because of the difficulties in the long-term nature of that work, decided again that the time was not right, that nature would not be kind with respect to the development of that program.

And as a consequence we went to DOE and pointed out that Gould itself would certainly not be willing to expend any more funds in this area for the time being, until we found out a little more about the science, and so the program was stopped.

In addition, in the zinc bromine area, Gould over the last 2 years has substantially changed its strategy away from heavy equipment toward electronic equipment, consequently, have been working with DOE and with EPRI, who has shared in the funding of our zinc bromine program, to find another contractor for that program to carry it on, because the promise is great, and the rate of advance of that particular battery system is very good, but it does not seem to be in the long-term interests of our company to pursue it, and so we would rather put our management and technical talent on other issues, but do not wish to either waste the Government's money or the technical efforts of our people to see that die. We would rather see it transferred.

Thank you.

Mrs. BOUQUARD. Dr. Pangborn, I will get to you the next time around. My time is up. Mr. Lujan.

Mr. LUJAN. Thank you, Madam Chairman.

I have a lot of trouble with trying to assure that we have sufficient funding for R. & D. All of us on this committee are very much in favor of various R. & D. programs, particularly in basic research. I am also bothered—well, let me further expand on that.

Since the members of this committee are all very much inclined toward all of these different programs that we authorize—and I have two of the national laboratories in my home district—I don't want to see those research funds cut so low that they adversely affect the work being done. But then I am troubled by another thing I hear at hearings such as this, which is that notwithstanding the tight budget situation that we have, the Government still continues to fund utility projects.

We do all kinds of things in the tax area; for example, for utilities, $750 of dividends are not taxed. That is to entice people to

invest in utilities. Any time any one of your companies spends a dime on research, the Federal Government is picking up 50 percent of it, 48 percent of it, whatever the tax bracket is, so that the Government is paying half of the risk in research anyway.

I had a research company come to me the other day to sell me a piece of the action on something, and of course I couldn't invest in it for obvious conflict of interest reasons, but if I were to invest $13,000, I could take $40,000 as a deduction on earnings, which, for someone in the 50 percent bracket, means that I would save $20,000 in income tax if I give them $13,000.

It seems we have all kinds of tax breaks, specifically in the energy storage business. Energy storage is certainly a big advantage to the utilities. I don't understand the reluctance, I don't see why there is that reluctance to spend their own money to do the research. They are going to make a lot of money on it afterward.

In response to a question as to what is done for peak loading, what really is done for peak loading is use the old facilities that the companies have left from the time when natural gas used to be so cheap. It is not that way anymore, so it would be advantageous to the utilities to spend their own money in doing research for energy storage. I would like to visit with you, any of you who want to discuss that subject, as to why there is that reluctance when there really exist big tax advantages to any utility who wants to do it.

Mr. PRY. Let me address the question, at least a part of your question relative to, as you say, the Government paying half of R. & D. expenses already. I think there is a problem with that concept. You cannot make a differentiation between R. & D. expenditures and let's say expenditures for updating or upgrading or even maintaining plant and equipment, for indeed research and development, in the same sense as maintenance and repair of plant and equipment is maintenance and repair of one's intellectual assets. It is the price of staying in business.

Consequently, research and development expenses I think have been viewed properly by both Government and the industry as a cost of doing business, not as a kind of thing outside the business stream, which is necessary in order to maintain a position in a marketplace.

Second, with respect to the question of utilities and their ability to make expenditures, I think you might well ask why is it that it is only post-1970 that the utilities and their servicing companies seem to have been unable to provide the long-range research and development required. Let me recount just a little bit of history on that question, because I was associated with an electrical manufacturer aimed at utilities for 25 years, General Electric.

If you look at the period between 1900 and 1970, a very interesting thing happened. Each plant that was installed, each piece of equipment that was installed, as a consequence of research and development during that period produced electricity at lower cost. The plant itself was lower in cost per kilowatt-hour produced than the previous plant.

Regulating agencies being as they are, agencies have some inertia, always lag by about a year or two. Rate changes as a consequence of those decreased costs lag too. Consequently, utilities were

able to pay for some of the first costs for first-of-a-kind plants to the manufacturing companies who expended their own funds on research and development for this area.

Post-1970, on the other hand, even without the immediate problem of the oil crisis, something else happened. The cost of the new plant, largely because of increased safety regulations as well as just increases in material costs and manufacturing costs, began to cost more than the plant that it supplanted.

Now, regulatory agencies maintained, unfortunately, the same kind of inertia, and so again a year or two passed prior to the time that rates were changed to absorb those increased costs. As a consequence, utilities in the United States particularly, were hard-pressed to provide for their own research and development or, indeed, to pay the first-of-a-kind cost to U.S. manufacturers who needed to recover those costs in their R. & D. expenses.

Mr. LUJAN. Dr. Pry, that is very interesting, but as a matter of fact there is a national phenomenon now that utilities are beginning to diversify, to go into the land development business, to go into all kind of other activities, mining activities, exploration activities. That tells me that what they are doing is taking the money that could be used for research to acquire some other properties.

Now it would seem to me that the first unit that comes up with a good storage system—and that shouldn't cost that much money; I think a utility, almost any sizable utility could afford to move forward with some kind of a storage facility—is going to be in a much, much better position than the rest of you.

All right, Mr. Bethel.

Mr. BETHEL. The utilities ought to speak for themselves, but I can't help but address that one. What we have seen happen in the last half a dozen years is that the successes that a utility achieves in greater operating efficiency and lowering their costs are passed on to the ratepayers. The failures that they encounter, on the other hand, because they have taken on a high-risk project, are passed on to the shareholders, and eminently, in my opinion, unfair regimen.

Mr. LUJAN. That is very true. As a matter of fact, in the bill that we are discussing now on the floor for the Alaska Natural Gas Pipeline, the big argument is whether we are going to have prebilling, so that they can——

Mr. BETHEL. I would like to continue, if I may, with a couple of points to build on prior comments. In the same vein, outlining what happened to the electric utility industry, the manufacturers find themselves now in a much less favorable position as far as being able to afford R. & D., because our business in T. & D. is driven by new generation installations, by housing starts, and by industrial and commercial construction.

Now, we know what has happened to new generation. There just isn't any to speak of, so that part of our business for the next 5 years in generation stepup transformers will be at a level of about one-fifth of what it was for the last 5 years.

The T. & D. industry, not just in the United States but pretty much around the world, is operating at 60 to 70 percent of capacity.

Mr. LUJAN. What is T. & D.?

Mr. BETHEL. Transmission and distribution. I am sorry, we fall into the slang of our own trades, all of us.

So that our afford level is quite seriously depressed.

Further, there is not a reluctance for us to spend. The amoung that my transmission and distribution group spent last year and this year and about what we will spend next year on research and development, technology perfection and application to new products is in total about 30 times what we have been getting in support from DOE this year and what we expect to get next year, so there is no reluctance for us to spend.

If I take the total, including EPRI and some direct support from utilities, then I still am spending three times as much of our earned dollars as I am getting in outside support. So you can't maintain that there is a reluctance to spend, but because of what we said earlier, we have got to spend on things with early payoff, just to stay alive. And if we spend on that, and we have an afford level that we can't exceed, then that, perforce, is going to eliminate the longer terms, the 5- to 10- to 15-year payoff projects.

Mr. LUJAN. Are you then saying that industry does invest in research, and that if the government won't spend increased amounts of money on research that will not hinder the research effort tremendously?

Mr. BETHEL. No, it's got to hinder in the long range, and no one here is advocating—we haven't talked about amounts of R. & D., but what I would like to see, is more or less a continuation of the EES funding levels at about the same as they were in 1979, 1980, and this year.

Mr. LEWIS. I would like to thank Dr. Pry and Mr. Bethel for explaining our point of view. I think they very succinctly described the position of the utilities.

One other point you raised, that utilities were not putting money into energy storage.

Mr. LUJAN. No, I didn't say that. I said they must have moneys that could be used in research, because they are now diversifying, most—I shouldn't say most because I don't know, but many utilities are fiversifying into other types of business.

Mr. LEWIS. There are two items there. One is, money is being put into research. We are going through a budget exercise similar to the one you are going through in the Federal Government, based on trying to reduce costs, but our research expenditures for 1982 and 1983 are in the neighborhood of $17, $18, $19 million per year.

In my formal statement I indicated the expenditures that Public Service had made in connection with the BEST facility are some $4.6 million and that the total industry investment in that facility is about 62 percent of the total funding, as part of a planned program to go over a number of years. Now we are at the point in the BEST facility program where the initial investment in experimental equipment can be put to use. However, one of the partners, the Federal Government has indicated its intent to withdraw from the program prior to achieving planned objectives. The result of this action is that neither the taxpayers nor the utility customers will realize benefits from the money invested.

The diversification that utilities are now looking into is based primarily on the rate of return to their investors. The money that

goes into research, if the companies are successful, as Mr. Bethel has pointed out, the money flows through back to the customers. If they are unsuccessful, the stockholders pick up the burden. By going to diversification and trying to work in industries that are not regulated, some of the return can stay with the investors.

Mr. LUJAN. Mr. Schneider, do you have something to say?

Mr. SCHNEIDER. I was prepared to repeat my earlier testimony, picking out two sentences from different pages, although your question addresses the question of diversification, and this hearing isn't really going into diversification in any great detail and we are not the experts to talk about it.

Mr. LUJAN. The only reason I bring it up is because of the moneys that could be put into research.

Mr. SCHNEIDER. I would like to respond by asking the question if you are in a healthy business, making a good return, in a business that you know about, why would you go looking for other businesses to invest in? Would it be perhaps because you could capture a higher rate of return in those businesses?

Mr. LUJAN. Maybe you can get somebody else to pick up the tab for research so you don't have to do it.

Mr. SCHNEIDER. That really doesn't appear to be the case. The problem today is that the utility sector has difficulty just making the normal business investments required to stay in the business of generating and delivering electricity. You are emphasizing the investor-owned utilities; and one of the utility groups in the investor-owned sector. There are other sectors in the utility business as well. There is the rural electric co-ops, the various public power associations, and the Federal Government.

If the utility industry again starts making a profit, perhaps there would be a benefit from the reduction in taxes, but in general, the issue is that the benefits and the risks in the utility sector are separated. As Mr. Lewis described, the risks are largely taken by the utility and its stockholders, the benefits largely accrue to the customer of the utility, because the public utility commissions control the rate of return that the utility experiences. As described earlier, recently the history has been one where each year we have faced increased costs. The public utility commissions are reluctant to see the electric rates go up, because people complain about their electric bills, even though the increases have been modest increases compared to the cost of oil and gas.

Mr. LUJAN. I don't have any problem with utilities or companies or anybody making a profit. I think that is great. What I am trying to do is just to lay a little groundwork, because those Government expenditures are going to be reduced, and I want to point out that, as a matter of fact, while we reduce the outlays, the moneys are still available through the tax credits.

Mr. SCHNEIDER. But it will take time for the improvements in the financial health to occur if the programs are successful. In other words, all of these benefits are not available today. It takes time to put programs in place and to see the improvements occur in the financial health of the industry that you are anticipating. They are not going to occur instantly.

Currently, there is, if you will, a builtup reservoir of non-economic situations in the utility industry as a whole, and it is

going to take time for the health of the industry to be restored. It is not going to happen overnight, and really the thrust of this testimony is not to encourage an enormous Federal role in energy R. & D., as I am sure all of us here agree with increased private sector participation in R. & D., but we recognize that things take time, that in some areas, long term may mean 10 or 15 years and not 50 years, and the R. & D. risks are high, and in a year where the prime hit 20 percent, it takes a rather substantial carrot out in the future to encourage an R. & D. investment.

Mr. PANGBORN. If I might have the chance to say something. I haven't had the opportunity to answer a question yet.

Mrs. BOUQUARD. Yout time is coming.

Mr. PANGBORN. Thank you. The Institute of Gas Technology, of course, is not a utility company and not a manufacturer, but we very closely observe the research expenditures of the utility industry and the supporting manufacturing companies. I think they have made their reasons rather clear about why they don't want to spend money for high-risk, high-reward ideas that may be of a long-term nature, and that they concentrate what research dollars they have in the near term.

We have to recognize something that is happening in this country and in the world in fuel usage: Fossil fuels provide over 90 percent of the energy supply that we are using in this country. We convert it to many things, electricity included, and fossil fuels by their very nature are inherently storable.

If they weren't, they would not have lain in the ground for something like 40 million years, and these are the fuels that we are using and consuming every day. As we consume them, they become more and more scarce, and their marginal costs increase; and these alternatives that we all like to think about, and that some of us do research on, become gradually more attractive and more promising.

The problem is that these alternative fuels are mostly renewables and are not storable by nature. As the shift continues from fossil fuels to renewable fuels, or to nuclear, which we have heard today is very difficult to use for suppling peak demands—and I would cite in my testimony the example of the Northeast, where 90 times more energy is needed in the winter than in the summer—we had best be doing some long-range research on energy storage and delivery systems that would be much different from the fossil fuel systems that we have today. Industry is telling us that they can't afford to do that. That is the area where Government research support is necessary.

Mr. LUJAN. Some of us think that perhaps that type of research isn't that expensive, that only Government can do it.

Mr. PANGBORN. Well, I don't know about the absolute magnitude of the dollars. The timeframe always seems to get in the way. The companies that we speak with and work with are interested in making research dollar investments, if the payoff is on a 5-year timeframe, and the timeframe seems to be much more important than the magnitude of the dollars.

Mr. LUJAN. I can understand that.

Mr. PANGBORN. They won't give us $5 for research that has a payoff beyond the year 2000.

Mr. LUJAN. I can understand that. I have got a basic business orientation rather than a Government orientation. In our business, we don't invest any money that we don't see a return on pretty quickly. It just seems to me that investment in energy storage for a utility is a damn good investment and one that, if I were president of a utility, I would be pursuing, because that is really what you need, and that is really that point I was trying to make.

Thank You, Madam Chairman.

Mrs. BOUQUARD. Thank you very much, Mr. Lujan.

Basically, I think what is being said insofar as storage systems are concerned, is that, right now, utilities are considered by some people to be a bum investment, because the rate of return is just not there, and because we cannot raise the rates to the utility consumers. Therefore, the R. & D. money must be confined to short-term R. & D. projects, where the near-term payoff will help in holding down rates and enhancing electric production. Therefore, much help is still needed in long-term programs such as the ones you mentioned, Dr. Schneider.

This is the role of the Federal Government within our free market system, when investors are not willing to put their money into a stock that will not pay a dividend perhaps for the next 20 or 30 years. Most people that buy stock intend to see a dividend before the next 20- or 30-year timeframe.

Mr. Lewis, can you tell me if Public Service intends to invest in nonutility areas?

Mr. LEWIS. This has been a subject of a great deal of discussion throughout the industry. There is an Edison Electric Institute study that is currently underway on diversification. The company has looked into these matters, and at this point, there has been no decision reached on investing in nonutility areas. The company has established several subsidiaries in support of its utility operations.

We have one subsidiary, the P.S.E. & G. Research Corp., that conducts our research and development program. We have another subsidiary, the Energy Development Corp., that is a gas exploration subsidiary developed in the late 1960's and early 1970's to assure a supply of gas to customers in New Jersey.

Mrs. BOUQUARD. Basically, your diversification allows you to put money into R. & D. if it is a longer term payoff, or into areas where there is no near-term return?

Mr. LEWIS. Currently we are wrestling with that very question as to what constitutes long term. We are trying to define right now what is longer term research. In the past, Public Service has put money into long-term projects. For example, we have put money into the fusion program, and we are probably one of the leading utilities to invest in fusion research and, when it gets to that point, development.

We are currently undergoing a budget exercise. The guidelines that were laid down for projects that are not research projects, are investments in construction expenditure projects which have to return money in 3 years. We have a 3-year payback as one of the criteria for current investments.

We are now looking into whether or not that same criterion should be applied to research programs. As you can see from the testimony today, there are not many research programs that would

have a payoff in a 3-year period. Some of the programs we support, such as fuel cells, batteries, the development of underground transmission cables, for the most part would not pay off in 3 years, and we are continuing funding in these areas.

Mrs. BOUQUARD. Thank you very much.

Dr. Pangborn, what do you think the impact will be on small business if the Federal Government does abandon the R. & D. participation in energy storage?

Mr. PANGBORN. Well, I think the impact will be quite severe, because the refractories and the brick and ceramic industry is composed of about 600 companies. There are about 3,000 kilns operating in the United States. They all have different requirements. It is a dispersed industry. They are not large companies individually. Yet collectively they consume a considerable amount of energy, and we feel that with this kind of research we could achieve a significant savings in energy consumption, something like a quarter of a quad, or 0.25 times 10 to the 15th Btu's.

If my arithmetic is right, that is something in the order of 40 million barrels of oil a year. But because there are so many small dispersed companies with differing requirements, none of them is able to really fund the kind of research that needs to be done. That is why we need some Federal support at this time, and in the interim, to carry forth this technology development until the applications are specified and fundamental research is taken care of. Then we would hope that even though they are small and dispersed and diversified in terms of need, there would be industry participation down the road.

Mrs. BOUQUARD. Dr. Schneider, you were talking about some of the projects that we are moving ahead with and that you were worried about, what would happen to them if the Federal Government withdrew its support. Really, what do you think the effects are going to be on our programs if we see them abandoned by the Federal Government?

Mr. SCHNEIDER. I guess the answer really depends on the extent to which the Federal Government's role is decreased, and that is a bit difficult for us——

Mrs. BOUQUARD. At this time, we are talking about a big zero. We are looking at the 1983 budget.

Mr. SCHNEIDER. I am willing then to respond on that basis, if we have really set up a scenario where we are talking about a zero budget in 1983.

Mrs. BOUQUARD. YES.

Mr. SCHNEIDER. The numbers I presented in my oral testimony, which is expanded upon somewhat in the written testimony, applies to both the electric energy systems and energy storage R. & D. programs. In energy storage we see a need for a national program to meet the objectives that have been developed over the last several years, this program requires an expenditure of about $50 million a year over the next several years.

This would result in the successful development of advanced battery systems for use by electric utilities for peak load or for load-leveling applications as well as resolve remaining issues in the mechanical energy storage systems of compressed air, underground pumped hydro, and would provide for small efforts in the longer

range systems that were discussed by the representative from IGT as well as some of the other systems that have not been talked about today.

The current EPRI effort is about $8 million a year. That is more than 3 percent of EPRI's budget. While it is small by Federal standards, it represents about 30 to 45 percent of the Federal program in the utility energy storage sector.

In addition, there has been significant utility support, an example being Public Service Electric & Gas, with its cofunding of the BEST facility. Added to this is about $20 million a year in development funds coming from private industry such as Gould previously, and Gulf & Western is a good example in zinc/chloride, along with others such as Exxon.

These moneys are largely constrained by the type of limitations on additional investment in the high-risk areas that were described earlier, so I see a substantial reduction in the total national effort in energy storage technology, precisely at a time when we have had some reasonable technical success in several of the systems, particularly in the advanced systems in zinc chloride, zinc bromide, and sodium sulfide.

Mrs. BOUQUARD. Do you think it would be economic for EPRI to continue their funding if federal funding was reduced?

Mr. SCHNEIDER. Yes, we would continue funding our programs. However, national progress would be at a reduced level and we would have to select very carefully. Instead of carrying forward several systems, if federal funding was reduced and there was not additional support from the private manufacturing sector, we would probably end up with one system being funded.

The probability of technical success gets substantially reduced, because each one of those systems probably only has a 50-percent chance or less of meeting both the technical and the cost targets that have to be met to make that technology feasible. You can develop the hardware, establish that it is scientifically feasible and prove its engineering principles, but it has got to be able to be sold on the marketplace in competition with other technologies. A similar situation exists with electric energy systems research.

Mrs. BOUQUARD. One question, Mr. Lewis, and I will refer back to Mr. Lujan. Will you be able to operate the battery test facility in New Jersey without federal help, without federal support?

Mr. LEWIS. The operation of the BEST facility is affected two ways by lack of federal support. One is the direct support for the facility. The second is support the Federal Government provides through the energy storage program to the developers of the batteries that are to be tested at the BEST facility.

In the first case—let's work with the second case first, in the development of the batteries. If the development of the batteries continues, and they are brought to the BEST facility for testing and evaluation, then it is likely that a means could be found whereby the facility could be placed in operation. In the first case, however, without the federal support the goals that were to be achieved I think would be lowered, and the programs would be delayed significantly in bringing the batteries to a commercial stage. That, then puts off the benefits that you would get from developing the bat-

tery systems and also affects the payback to the battery developers as well as the benefits to the customers.

In programs within the utility industry, there are a broad range of technologies. Today we have dealt primarily with two areas, electrical energy systems and energy storage. There are also programs concerning resource development, energy conversion, utilization and conservation, and there is a large program in environmental quality that is also funded by the utility industry.

As far as the application of our resources is concerned, in some programs such as the breeder reactor we have put about $6¼ million into that program. We have also put significant amounts of money into other energy conversion options, such as fuel cells and other forms of nuclear energy, fusion, high-temperature gas cooled reactors. Energy conservation has also been very important, because today it appears that the best way to maximize the return on dollars is to have energy conservation programs in the near term. These all are competing for the utility research dollar.

Mrs. BOUQUARD. Thank you very much. Mr. Lujan.

Mr. LUJAN. Thank you, Madam Chairman.

Just one comment, and that is that the whole energy storage system budget is under review. While we hear that it is going to be zeroed out, that policy is still in the making. It has been appealed. However, the one thing that we do know, and I suppose you would agree with it as businessmen, is that somehow or other we have to come to the realization that we can't spend more than we take in, and that is the goal of the Congress, of the administration, of everybody. I would imagine that none of you would disagree with that goal.

So with that goal in mind, we are going to have to cut somewhere. If, for example, it was determined that maybe we ought to cut energy storage systems in half to $20 million instead of cutting it by $1 million, as we have this year, we could sit here and think, oh, well, fine, we would like to take it back up to the $41 million, but in what other area are we going to cut $20 million to make up that $20 million that we are putting back in for energy storage.

Do any of you have any suggestions that you might help us with in our dilemma as to what would be more worthy a candidate of cutting than perhaps energy storage systems?

Mr. BETHEL. I am not a spokesman for energy storage because that is not part of what I am involved in, but in my field of transmission and distribution, if you look at what the expenditures have been by DOE, you will find that R. & D. support for energy sources of all sorts has outweighed—I always carried a number of 100 to 1. I think I heard earlier today the number of 200 to 1, the expenditures on energy sources versus the expenditures on energy distribution.

As I said in my testimony, through conservation, by improving the efficiency of transmission and distribution, we have as great a probability of mitigating our energy problem as we do with some of the more exotic generation schemes, and I think a more equitable spreading of whatever the budget can afford amongst all of the technologies that can make a real contribution, and make it relatively soon, is a way to give us the support that we think we need.

Mr. LUJAN. You make an excellent case for energy systems research, no question about that. We would not disagree with you, but then we get down to the bottom line of who would be a worthier candidate to cut than energy systems; where are we going to get it. And that is something that we face here, very frankly. We get a certain amount of pot, so to speak, to divide amongst all of the different research activities of the Government, so I am just trying to get some guidance from you as to where we might make those cuts.

Mr. PRY. I share your problem almost daily, as a matter of fact, in my own environment, and what one must do—perhaps I misunderstood you in your remarks, that one should share or spread the funds. I personally believe in my own operation that I try to target those funds where they will have the greatest possible leverage.

Now, the difficulty with that in an industrial environment, and currently in the Government environment, is you tend to look—because all of us have constituents, you tend to look at those that will have the most immediate obvious leverage.

I think what we are proposing today or what we are suggesting today, again, where I am vulnerable in any industrial climate, is to operate on two principles: leverage of the Government dollar, because one must look at what industry is spending as well. In some areas like lead acid battery research, for example, industry is spending so much money in this fairly mature technology that I think it is inappropriate that Government spend money in lead acid technology for near-term benefit.

On the other hand, if one takes the other extreme with respect to something like fusion research, I think there is no question of the long-term leverage of these Government expenditures for the benefit of the public, for the general public good. It is not an easy question, not at all.

I personally believe in stopping things, as I pointed out to you. I have, where I believed that that leverage was not present in my own company, and I suggest the Government must go through that same painful exercise in looking at what it is possible to spend, in looking at the maximum leverage that you can get, balanced short and long term, for the additional dollars that the Government puts into an effort over and above what industry spends.

Mr. LUJAN. Thank you.

Mrs. BOUQUARD. Thank you very much, Mr. Lujan.

We want to thank our very valuable staff, Miss Freiwald, Mr. Wallace, and Mr. Williams, for their help in the hearings today.

Mr. Williams, do you have any questions of our witnesses?

Mr. WILLIAMS. I don't think so.

Mrs. BOUQUARD. Again, thank you, gentlemen, for sharing with us your wisdom, your knowledge, and we appreciate your being with us. The subcommittee is adjourned.

[Whereupon, at 3:40 p.m., the subcommittee adjourned.]

II. ASSOCIATED CORRESPONDENCE

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December 4, 1981

Mr. David A. Stockman
Director
Office of Management and Budget
Executive Office Building
Washington, D. C. 20503

Dear Mr. Stockman:

I will appreciate your assistance in designating Mr. Fred Khedouri, Associate Director for Natural Resources, Energy and Science, to testify at our ERP Subcommittee oversight hearing next Tuesday, November 8, 1981. The hearing will be held on the Department of Energy's Energy Storage and Electric Energy Systems programs and will take place at 1:30 p.m. in Room 2325 of the Rayburn House Office Building.

I recognize that the hearing is only four days away. However, the Subcommittee has just received information on OMB passbacks to DOE indicating an abrupt termination of these programs in Fiscal Year 1983. Moreover, the history of reduction in these programs for FY 1982 in the budget submission and September amendment suggests that termination has been the OMB goal from the outset.

The Subcommittee recognizes the need for reducing federal budgets, but we have great concern that the termination of a federal role in these programs is not in the national interest. The research and development budget for electrical power generation is on the order of $2 billion, and yet this policy suggests that there should be no federal funding for research in storing energy or transmitting it to the end-user.

We would expect that Mr. Khedouri's testimony would outline the policy rationale for this budget action. The Subcommittee understand that he should have no trouble articulating your OMB policy views on the federal role in energy research and development.

We look forward to OMB's participation in this hearing.

Sincerely,

Marilyn L. Bouquard

MARILYN L. BOUQUARD, Chairman
Subcommittee on Energy
Research and Productio

MLB:Wcg

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF MANAGEMENT AND BUDGET
WASHINGTON, D.C. 20503

December 4, 1981

Honorable Marilyn L. Bouquard
Chairman, Subcommitee on Energy
Research and Production
Committee on Science and
Technology
U.S. House of Representatives
Washington, D.C. 20515

Dear Chairman Bouquard:

I regret that our Associate Director for Natural Resources, Energy and Science cannot appear at your oversight hearing next Tuesday, December 8.

As you know, the President submits his FY 1983 budget to the Congress in late January. Until that time we must maintain the confidentiality of the budget in order to permit the President to receive the counsel of his advisors and approve the program that he will recommend to the Congress.

I would also note that the post that Mr. Khedouri occupies is not one that requires confirmation by the Senate. We do not believe it is appropriate for Executive Office of the President staff other than those who occupy confirmed positions to testify before the Congress.

I am certain that after the President's budget is transmitted to the Congress, the appropriate officials of the Department of Energy would be pleased to discuss with you those programs within the jurisdiction of your Subcommittee.

Sincerely,

David A. Stockman

David A. Stockman
Director

MARILYN LLOYD BOUQUARD
3D DISTRICT, TENNESSEE

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November 5, 1981

Joseph J. Tribble, Assistant Secretary
for Conservation & Renewable Energy
U. S. Department of Energy
Washington, D.C. 20585

Dear Mr. Tribble:

I am pleased to invite you to testify at an oversight hearing on the Department of Energy's Energy Storage and Electrical Energy Systems Programs. The hearing is scheduled to be held on November 18, 1981 at 1:30 p.m. in Room 2325 of the Rayburn House Office Building.

The Committee is seriously concerned about possible reductions in these two research programs. The need for a stronger economy is certainly pressing, but budget reductions alone will not be economical in the long-term if investments are not made in future technology. I would like, therefore, for you to present in detail the proposed reductions in both programs for FY'82 and FY'83, the Administration's basis for reducing or terminating specific projects, the investments made to date on each one to be terminated and the potential impacts, particularly with reference to future consumer costs and decreased foreign market penetration by American industry. Since these reductions are presumably based on industry assuming responsibility for research, please substantiate this position.

Your written statement may be as long as you feel necessary but we ask that your oral presentation be limited to about 10 minutes in order to provide sufficient time for questioning by Subcommittee Members. Additional information regarding the preparation of testimony is enclosed for your information. If you have any questions, please call Mr. Ron Williams of the Committee staff at 225-1178.

Sincerely,

MARILYN L. BOUQUARD, Chairman
Subcommittee on Energy Research
and Production

MLB:Wjs
Enclosure

MARILYN LLOYD BOUQUARD
3D DISTRICT, TENNESSEE

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November 10, 1981

Honorable James B. Edwards
Secretary of Energy
Department of Energy
Washington, D.C. 20585

Dear Secretary Edwards:

The Subcommittee on Energy Research and Production plans to hold an oversight hearing on Energy Storage and Electric Energy Systems Programs on December 8, 1981 at 1:30 p.m. in Room 2325 of the Rayburn House Office Building.

I would appreciate it if you would designate a DOE witness to testify before the Subcommittee and formally present the Administration's position on research and development in Energy Storage and Electric Energy Systems. We had invited Mr. Joseph J. Tribble to be a witness since he was in a strong position to know the plans of the Administration as well as the program areas, but DOE Congressional Relations has now informed me that Mr. Tribble will not be able to testify because of a conflict in schedule.

Sincerely,

Marilyn L. Bouquard

MARILYN L. BOUQUARD, Chairman
Subcommittee on Energy Research
and Production

MLB:Wjs

Department of Energy
Washington, D.C. 20585

December 7, 1981

Honorable Marilyn Lloyd Bouquard
Chairman, Subcommittee on Energy
Research and Production
Committee on Science and Technology
House of Representatives
Washington, D.C. 20515

Dear Madam Chairman:

I am writing with regard to the hearing you have scheduled for December 8 on the Department's Energy Storage and Electrical Energy Systems Programs.

I regret that we were unable to work out a mutually satisfactory arrangement for providing a departmental witness at this hearing. As you know, Assistant Secretary Tribble had scheduled an intensive field trip to several of our national laboratories some time ago, a trip that he had already postponed from earlier this year, and, because of prior obligations of my own, I was not able to appear as a substitute witness. We had designated Deputy Assistant Secretary Maxine Savitz as the logical spokeswoman in the absence of Mr. Tribble and myself. She is a skilled manager, a seasoned witness, and an expert in the programs of concern to you.

While our schedules did not permit our appearance tomorrow, Mr. Tribble or I would be glad to meet with you at a mutually convenient time to discuss the details of the FY 1982 programs and to outline the areas we intend to emphasize in the future.

I appreciate your interest in these programs, and hope this meeting will be responsive to your Members' concerns.

Sincerely,

Guy W. Fiske
Under Secretary

Westinghouse
Electric Corporation

Transmission and Distribution

A L Bethel
Executive Vice President

Westinghouse Building
Gateway Center
Pittsburgh Pennsylvania 15222
412-255-3502

November 30, 1981

Ms. Marilyn L. Bouquard, Chairman
Subcommittee on Energy Research
and Production
Committee on Science and Technology
U.S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D. C. 20515

Dear Ms. Bouquard:

I am pleased to accept your invitation of November 24, 1981 to testify at an oversight hearing on the Department of Energy's Energy Storage and Electrical Energy Systems Programs on December 8, 1981.

In my opinion, the subjects to be reviewed are very important to the economic well-being of this country, and I welcome the opportunity to give you my view and perspective regarding them.

Sincerely yours,

A L Bethel/jc

jc

PSE&G Research Corporation

80 Park Plaza Newark New Jersey 07101 Phone 201/430-7000

November 30, 1981

The Honorable Marilyn L. Bouquard
Chairman, Subcommittee on Energy
Research and Production
Rayburn House Office Building
Suite 2321
Washington, DC 20515

Dear Congresswoman Bouquard:

TESTIMONY BEFORE THE SUBCOMMITTEE
ON ENERGY RESEARCH AND PRODUCTION

I am pleased to accept your invitation to testify at the oversight hearing on the Department of Energy's Energy Storage and Electrical Energy Systems Programs. My testimony will include:

1. A brief discussion of electrochemical energy storage and how the BEST Facility can advance this technology;
2. The design and planning of utility systems to provide low-cost reliable power to the consumer;
3. The financial problems faced by utilities; and
4. The limits of utility funding for Research and Development.

I understand that t hearing is scheduled to be held on December 8, 1981, at 1:30 P.M. in Room 2325 of the Rayburn House Office Building. In addition, 75 copies of my testimony and resume will be sent to Mr. Ron Williams at least 24 hours in advance of the hearing.

If you have any questions, I may be contacted directly at (201) 430-6634.

Sincerely,

Peter A Lewis/s

Peter A Lewis
Manager - Applied Systems, R&D

PAL:MN

cc: R. Williams

90-261 O—82——7

ELECTRIC POWER RESEARCH INSTITUTE

December 1, 1981

EPRI

The Honorable Marilyn L. Bouquard
Chairman
Subcommittee on Energy Research
and Production
Committee on Science and Technology
U.S. House of Representatives
Suite 2321 Rayburn House Office
Building
Washington, D.C. 20515

Dear Representative Bouquard:

Thank you for your letter of November 24, 1981. EPRI will be pleased to provide a witness for the hearings which your Subcommittee will hold on December 8, 1981 on Energy Storage and Electric Energy Systems.

Dr. Thomas Schneider, assistant director of EPRI's Energy Management Utilization Division, will present our testimony and answer questions on energy storage. He will be accompanied by Mr. Richard Steiner, director of EPRI's Power Systems Department of the Electrical Systems Division, who will be available to answer questions on electrical systems.

We appreciate your invitation and look forward to meeting with your Subcommittee next week.

Sincerely,

Richard L. Rudman
Director
Information Services

RLR:hm

cc: Robert Loftness

III. LIBRARY OF CONGRESS REPORT

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Washington, D.C. 20540

December 7, 1981

TO : Committee on Science and Technology
Subcommittee on Energy Research and Production
Attention: Ron Williams

FROM : Fred J. Sissine FJS
Analyst in Energy Technology
Science Policy Research Division

SUBJECT : Energy Storage

This responds to your request of November 11, and our subsequent conservations concerning the DOE Energy Storage Program.

Enclosed is a copy of a report on legislation, programs, and policies in the energy storage area. This report should provide the information which you are seeking on the development and current status of the Energy Storage Program.

If we can be of further assistance, please do not hesitate to call (287-7038).

Enclosure

FJS(JGM/GHM)fs

Congressional Research Service
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Washington, D.C. 20540

ENERGY STORAGE: LEGISLATION, PROGRAMS, AND POLICIES

Fred J. Sissine
Analyst in Energy Technology
Science Policy Research Division
December 1981

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I. INTRODUCTION

Since the early 1970s, there has been an increasing awareness that energy storage systems can be an important part of the Nation's effort to decrease its dependence on oil and natural gas and increase its use of alternative fuels. Energy storage can extend the usefulness of renewable resources, such as solar and wind energy, or it can improve the efficiency of oil, gas, coal, and nuclear energy use. Recognition of the opportunities presented by an expanded use of energy storage led the Federal Government to steadily increase its support for storage research, development, and demonstration during the period from 1973 through 1980.

As part of an effort to bring Federal spending under control, the Reagan Administration's FY82 budget request to Congress included some dramatic reductions in the budget authority established for the FY 1981 and FY 1982 energy storage program under the Carter Administration. The Reagan Administration reasoned that decontrol of oil and natural gas prices would provide sufficient incentive for the private sector to pick up demonstration and commercialization activities in the energy storage area. The Federal storage program, then, would emphasize long-term R&D. Continuing its budget reduction initiative, the Administration recently revised its FY82 budget request, asking only for enough funding to terminate the energy storage program during the early part of the fiscal year. 1/

1/ U.S. Dept. of Energy. FY 1982 Budget Amendment to the Congress. Oct. 1981. (Revised Nov. 6, 1981) p. 107-109A.

The continued existence of the entire storage program has emerged as the primary issue of storage policy.

The House Science and Technology Committee's Subcommittee on Energy Research and Production examined the Administration's rationale and explored the possible impacts of these reductions in its FY82 authorization hearings held during March 1981. 2/ This report relies heavily on the testimony given at these hearings to characterize several major issues affecting energy storage policy.

2/ U.S. Congress. House. Committee on Science and Technology. Subcommittee on Energy Research and Production. Department of Energy Authorization for fiscal year 1982. Hearings, 97th Cong., 1st Sess., March 16, 1981. Washington, U.S. Govt. Print. Off., 1981. p. 530. (Hereafter cited as Hearings)

II. THE NEED FOR ENERGY STORAGE

After the energy potential of a natural resource is converted into a more directly usable form, such as heat or electricity, it may be necessary to store it for later use. Thus, energy storage is an intermediate phase of the energy consumption process which occurs after production and before final utilization. An energy storage system acts as a buffer mechanism. It accumulates surplus energy supplies when production exceeds demand, and provides supplemental energy when production falls below demand. Storage systems are important for many sectors of the economy since energy use can vary considerably with the time of day, from one day to another, and from one season to the next.

Potential Applications

Oil import reductions and improved energy use efficiencies can be derived from the application of energy storage technology to utility load-leveling, end-use load-leveling, and the development of electric vehicles. In the utility sector, the daily, weekly, and seasonal variations in electric power demands often cause baseload powerplants to be used at less than 60% of their generating capacity. 3/ Intermediate- and peak-load powerplants, fired by petroleum fuels, are currently used to provide the additional requirements of peak demand periods. However, there are four reasons for increasing the use of baseload capacity to displace the use of these other facilities: baseload plants are more efficient, less costly to operate, have better pollution controls, and can be converted to use

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3/ Kalhammer, Fritz R. Energy-Storage Systems. Scientific American, v. 241, Dec. 1979. p. 56.

alternate fuels. The use of baseload capacity can be increased by employing energy storage during the time of off-peak demand. Since this activity results in a shift which evens out a utility's load profile, it is known as a load-leveling or load management technique. At different potential storage sites in the power distribution network--central stations, substations, and end-use sites--different types of storage technologies can be used for this purpose. DOE estimates that each 1% increase in the market penetration of this type of energy storage capability can provide savings of about $2.5 billion in capital expenditures by the utility industry. 4/

The use of storage technology in the industrial sector can also contribute to oil displacement and improved energy efficiency. For many industries, battery storage can be used on-site or at utility grid substations to reduce peak electrical demands. 5/ Also, electrochemical storage techniques can be used to improve process efficiencies in electrolytic industries, such as aluminum manufacturing. 6/ Thermal energy storage is needed in industries where there is a time or rate mismatch between heat availability and heat demand. 7/ Residual process heat may also be stored for use in a district heating system. 8/ Additionally, battery storage

---

4/ Net Savings Due to Installation of Energy Storage Devices in the Utility-Customer System. Personal communication from Mr. James Chalmers, Project Engineer, Chemical Energy Technology Directorate, The Aerospace Corporation. Nov. 12, 1981.

5/ U.S. Depart. of Energy. Energy Storage Systems: Program Summary Document. Jan. 1980. Washington, U.S. Govt. Print. Off., 1980. p. III-48.

6/ Ibid, p. III-50.

7/ Ibid, p. III-3.

8/ Meyer, Charles F. Potential Benefits of Thermal Energy Storage in the Proposed Twin Cities District Heating-Cogeneration System. (DOE/Oak Ridge National Laboratory, Oak Ridge, Tenn.) ORNL/Sub-7604/2. Oct. 1979. p. 3-2.

and on-site thermal storage can be used to even out a changing ratio of power to heat demands in order to enhance the prospects for using a cogeneration system at an industrial site. 9/

The use of storage technology in residential and commercial sectors can also reduce oil consumption and increase energy efficiency. Load-leveling can be achieved for these sectors through the use of daily and seasonal storage used in conjunction with utility power grids and renewable energy sources. 10/ Off-peak electric power produced by utility baseload plants can be stored at building sites to supply peak demands for space heating, air conditioning, and hot water heating. 11/ Additionally, end-use storage systems can increase the use of solar and wind energy by improving the continuity of energy supply from on-site technologies. 12/

For the transportation sector, electrochemical storage in rechargeable batteries and fuel cells is being explored for use in electric and hybrid vehicles. The development of such vehicles could shift fuel dependence from oil (in the form of gasoline) to coal and nuclear energy used to produce electrical power. 13/

9/ Ibid.

10/ DOE, Energy Storage Systems, p. III-3 to III-10.

11/ Swisher, James H. Concept Statement for Distributed Thermal Storage. In Peak-Load Pricing and Thermal Energy Storage. Division of Energy Storage Systems, Dept. of Energy, July 15-17, 1979. p. 55.

12/ DOE, Energy Storage Systems, p. III-3.

13/ DOE, Energy Storage Systems, p. I-1.

Barriers

For each type of storage technology, there are characteristic technical, environmental, or economic barriers which R&D efforts seek to overcome. Research on batteries, for example, is aimed at improving system energy density, power density, rechargeability and life cycle: all of which would reduce system costs. For underground storage systems, barriers arise primarily from concerns about impacts on land use and water quality and the possibilities of subsidence (sinking of land surface). Additionally, R&D on hydrogen, thermal, and magnetic storage systems is focused on improving the cost-effectiveness ratio of materials and technology expense to the value of energy savings.

Potential Savings

In summary, the changing conditions of energy economics together with an R&D-induced reduction of technical and environmental barriers may enable energy storage systems to extend the period of useful operation of utilities' most energy-efficient and cost-effective equipment, increase the usefulnesses of industrial reject heat, and improve the capacity of renewable resources to provide a continuous energy supply. Through these applications, storage technology can be used to conserve energy and to substitute alternative fuels for petroleum fuels. It has been estimated that the research, development, and implementation of energy storage technologies could provide up to 6.7 quads (quadrillion BTUs) of energy savings by the year 2000 through conservation and fuel shifting (equivalent to saving 3.4 million barrels of oil per day). 14/

14/ Ibid.

III. THE DOE ENERGY STORAGE PROGRAM

The Federal Government has supported work on energy storage systems since 1973. [See Table Below] The current goal of the Energy Storage Research and Development program is to undertake advanced research on long-term, high-risk, but potentially high payoff storage technologies that will improve the linkages between energy sources and the processes of conversion, distribution, and end-use. 15/ The program emphasis under the Reagan Administration is based on an assumption that the marketplace will determine private industry's development of near term technologies into commercial hardware. 16/ In the present program under the Reagan Administration, technologies for chemical, thermal, mechanical, and magnetic storage are being explored for applications to industry, buildings, utilities, and transportation. The DOE Energy Storage Program serves as the nucleus for virtually all research and development related to energy storage within the agency. Thus, the program supports not only the utility, end-use, and renewable energy applications related to Conservation and Renewable Energy programs, but also supports some of the missions of the Nuclear Power and Fossil Fuel programs. 17/

15/ U.S. Department of Energy. Energy Storage Systems: Program Summary Document. Apr. 1981. Washington, U.S. Govt. Print. Off., 1981. (in press) p. III-B-1.

16/ Hearings, p. 532.

17/ DOE, Energy Storage Systems, 1980, p. III-2.

CRS-8

ENERGY STORAGE FUNDING HISTORY

DOE Spending from 1973 to 1980*

(in millions)

Fiscal Year	Battery Program	Thermal & Mechanical Program	Totals
1973	$ 0.9	--	$ 0.9
1974	3.4	--	3.4
1975	5.8	$ 1.2	7.0
1976	13.6	9.8	23.4
1977	19.5	17.7	37.2
1978	22.5	26.6	49.1
1979	30.6	32.6	63.2
1980	40.6	31.9	72.5
1981**	27.8	24.1	51.9
Totals	164.7	143.9	308.6

*Budget figures for 1973-1975 represent outlays by the Atomic Energy Commission, and figures for 1976-1977 represent outlays by the Energy Research & Development Administration.

**Budget figures for FY81 take into account $19.5 million in rescissions initiated by the Reagan Administration.

The Administration's FY82 budget request for the Energy Storage Program totalled $38.0 million, which was $33.4 million below the FY81 appropriation before the rescission. At the subprogram level, the Administration requested $25.6 million for the Battery Program, $11.9 million for the Thermal and Mechanical Program, and $0.5 million for program management. 18/ Congress approved this sharp reduction in the Energy Storage Program when it passed the FY82 DOE authorization bill (contained in P.L. 97-35, the Omnibus Budget Reconciliation Act), adding only $3 million to the Thermal and Mechanical Program. 19/

Before Congress could complete action on the FY82 DOE appropriations bill (H.R. 4144), the Administration amended its FY82 budget request, asking only for enough funding to terminate program operations. 20/ The revised proposal asked for $5.1 million for the Battery Program, $4.6 million for the Thermal and Mechanical Program, and $0.5 million for program management. Congress has apparently rejected this termination move by the Administration. H.R. 4144 was reported from conference on November 19 with a recommendation that funds be appropriated for the Energy Storage Program at the level authorized. 21/

18/ Personal Communication, Jeff Nita, Congressional Budget Office. Dec. 3, 1981.

19/ U.S. Congress. House. Committee of Conference. Omnibus Budget Reconciliation Act of 1981; report pursuant to H.R. 3982, 97th Cong., 1st Sess. Washington, U.S. Govt. Print. Off., 1981. 1047 p. (97th Cong., 1st Sess. House. Report no. 97-208, part 2) p. 835.

20/ DOE, FY 1982 Budget Amendment, p. 107-109A.

21/ U.S. Congress. House. Committee of Conference. Making appropriations for energy and water development for the fiscal year ending September 30, 1982, and for other purposes; report pursuant to H.R. 4144, 97th Cong., 1st Sess. Washington, U.S. Govt. Print. Off., 1981. 44 p. (97th Cong., 1st Sess. House. Report no. 97-345) p. 26.

IV. CONGRESSIONAL INTEREST

Legislation to support the research, development, and demonstration of energy storage technology has been forthcoming since the 93rd Congress.

93rd CONGRESS

Congressional action focused on energy storage was first expressed in the Federal Nonnuclear Energy Research and Development Act of 1974 (P.L. 93-577). This law directed the Administrator of the Energy Research and Development Administration (ERDA) to establish program activities involving the research and development of small thermal storage systems, inertial energy storage systems, fuel cells for utilities, and batteries which could serve as alternatives to the internal combustion engine. Additionally, the Solar Heating and Cooling Demonstration Act of 1974 (P.L. 93-409) established a program which includes a requirement for the development and demonstration of thermal storage to be used with residential solar equipment.

94th CONGRESS

The Electric Hybrid Vehicle Research, Development, and Demonstration Act of 1976 (P.L. 94-413) authorized ERDA to promote electric vehicle technology development and commercialization. The Act defines electric vehicle R&D to include energy storage technology, especially batteries. The Act also contains provisions which authorized the agency to accumulate

demonstration data and to make loan guarantees available for these R&D activities.

95th CONGRESS

The Solar Photovoltaic Energy Research, Development, and Demonstration Act of 1978 (P.L. 95-590) includes provisions which require R, D, and D of equipment for the storage of electricity as part of the photovoltaic effort. In addition, the National Energy Conservation Policy Act (P.L. 95-619) authorizes support for the implementation of energy storage devices used for load management by utilities. It also establishes support for devices which utilize solar energy or windpower to provide residential space heating and cooling or water heating. The acquisition of storage equipment for use with photovoltaic systems installed in Federal buildings is also authorized. Finally, the Act establishes programs to encourage industrial conservation efforts which may include the development and use of electrolytic equipment.

Three other bills related to energy storage were introduced during the 95th Congress, but did not become public law. One bill (H.R. 11521/ Allen) would have established a National Contest for the Invention and Development of an Efficient and Cost-Effective Electric Energy Storage Facility. This bill would have created a national award of $10 million for the development of a safe, cost-effective, long-term electric energy storage technology. Another bill (S.3557/ McClure) set forth a method for computing the average fleet fuel economy standards for motor vehicle manufacturers who include electric vehicles in their fleets. A third bill (H.R. 5500/ McCormack) proposed the creation of tax incentives for the purchase of electric vehicles.

96th CONGRESS

The Ocean Thermal Energy Conversion Research, Development, and Demonstration Act (P.L. 96-310) sets goals and establishes a program strategy for conversion of ocean thermal energy to energy carriers which may include hydrogen and molten salts (storage batteries). The Energy Security Act (P.L. 96-294) includes two provisions related to energy storage. For the purposes of the Synfuels Corporation, water which has been electrolyzed to produce hydrogen, is to be considered as a source of synthetic fuel along with coal, shale, and tar sands. Additionally, for the purposes of the Solar Energy and Energy Conservation Bank, financial assistance may be provided for the purchase and installation of devices associated with load management techniques.

Three other bills related to energy storage were introduced during the 96th Congress, but did not become law. One bill (S. 624/McClure, H.R. 3718/Corcoran) reintroduced the proposal that electric vehicle manufacturers be encouraged by allowing them to incorporate calculations of equivalent petroleum fuel use by electric vehicles into the average fuel economy calculations for its entire fleet of manufactured vehicles. A second bill (S. 3185/Matsunaga) proposed the establishment of a $0.5 billion program of accelerated research, development, and demonstration of advanced battery technology for use in electric vehicles, electrical load-leveling, and storage of solar-generated electricity. A third bill (H.R. 5399/Grassley) proposed support for R,D, and D of hydrogen production and storage.

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97th CONGRESS

Two bills related to energy storage technology have been introduced during the 97th Congress. One bill (S.456/ Matsunaga) reintroduces a proposal for the establishment of a $0.5 billion program of R,D, and D of advanced battery technology. A second bill (S.731/ Glenn) proposes the creation of a $0.75 billion program of research, development, and demonstration of electrical, chemical, thermal, and mechanical energy storage technologies for use in transportation, industrial processes, utility applications, and building heating and cooling systems. Neither bill has been acted upon.

V. BASIC ISSUES FOR ENERGY STORAGE

The budget proposals made by the Reagan Administration for FY81 and FY82 have resulted in significant reductions and terminations of DOE program activities in the energy storage area. At recent hearings of the Subcommittee on Energy Research and Production of the House Science and Technology Committee, testimony was taken on the Administration's rationale for program changes and on the possible impacts of these changes. Dr. Maxine Savitz, Deputy Assistant Secretary for Conservation at the Department of Energy, testified on the changing Federal role that the Administration envisions for the Energy Storage Program.

Dr. Savitz sketched out the Administration's strategy to increase the involvement of the private sector in fuel shifting and energy conservation activities, including energy storage development. She testified that:

> the President's program emphasizes the lifting of unnecessary regulations on energy consumption. With energy price decontrol and the deregulation of energy consumption, the private sector can be expected to be much more active in the area of energy conservation. This free market activity should be enhanced by the [A]dministration's continuing support of energy tax credits and new initiatives, such as accelerated depreciation for capital equipment. 22/

22/ Hearings, p. 514.

In regard to the role for the Federal Government in these areas, Dr. Savitz emphasized the Administration's focus on long-term R&D. She stated that:

> It is only in the areas where the private sector cannot be expected to respond that the Federal Government should become involved. One such area is long-term generic research and development, where the risks are large and the payback period is long. The [A]dministration believes that this kind of research and development deserves continuing support even in periods of severe budgetary constraints... It is with this philosophical framework in mind that we have changed the direction of certain programs. 23/

Dr. Savitz summarized how the thrust of this framework would apply specifically to the Energy Storage Program. She stated that, "The emphasis in the program will be on developing the technology base needed for industry's research and development effort and on long-term research and development since nearer term storage technologies will be developed by the private sector as the market develops." 24/

However, some of the witnesses at the hearings testified that the Administration's proposed changes in the Energy Storage Program could inhibit the involvement of the private sector and cause the flow of energy storage R&D to be interrupted. Additionally, some of the testimony indicated that cuts in the energy storage budget may affect the U.S. position in the international marketplace for storage equipment and the development of other conservation and renewable energy technologies.

23/ Ibid.

24/ Ibid, p. 532.

SIGNIFICANCE TO CONSERVATION AND RENEWABLES

Mr. John J. Brogran, Director of the DOE Office of Advanced Conservation Technologies, testified to the connection between the energy storage program and other renewable energy programs. He pointed out that, "Most of the storage activites that are aimed at solar applications are jointly supported by the solar program within the Department, especially thermal storage and battery storage." 25/ Dr. Savitz emphasized the importance of the connection between programs. She stated that, "The thing is, the storage area particularly is really a supporting technology that enables a lot of the technology developments that are going on in the other renewables and in the conservation areas to be successful...For example, with the solar type program, by having adequate storage, you can extend the time or reduce the time that you need actual sunlight, so that you help make those systems cost-effective." 26/ She further stated that:

> In order to get a viable electric vehicle system, we are going to need good batteries, so that the two, the storage program particularly is a partnership program with all the renewables and the end use areas to extend both the reliability, the life, and also in some cases be able to reduce the cost, because if you can store this energy for longer periods of time, you may be able to have a smaller set of collectors. 27/

25/ Ibid, p. 560.

26/ Ibid, p. 562.

27/ Ibid.

INTERNATIONAL COMPETITION

At these hearings, Rep. Wolpe indicated his concern for the U.S. position in domestic and international marketplaces for energy storage equipment. He expressed a desire to understand the rationale for drastic reductions in the energy storage program since, "...much of the work being eliminated is long-range research and industry will be unable to fill the resulting back vacuum which, in the long run, could result in importation of advanced [storage] technology." 28/ He also stated a concern that, "...the elimination of a large measure of academic research in these fields [storage, electric systems, and small hydro] will put the United States proportionately further behind Japan, the Soviet Union, and Western Europe in development of energy manpower that can keep our technology healthy and competitive." 29/ Dr. Savitz provided information on a particular instance of foreign competition in storage equipment. She indicated that R&D of the sodium-sulfur battery was being aggressively pursued by government supported efforts in Japan, Germany, and Great Britain. 30/

R&D CHANGES DUE TO BUDGET CUTBACKS

Several cancellations and program reductions have resulted from the FY81 rescissions and FY82 budget changes made by the Reagan Administration. For the thermal subprograms, the FY81 changes included the cancellation of the technology development effort for industrial waste heat storage,

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28/ Ibid, p. 513.

29/ Ibid.

30/ Ibid, p. 544.

and reductions in chemical/hydrogen storage, heat exchangers for district heating, and flywheel development. For mechanical subprograms, demonstrations of underground pumped hydro and underground compressed air storage were cancelled. The subprogram focused on the development of large-scale superconducting magnetic storage was cancelled. For electrochemical subprograms, the dispersed battery applications effort was terminated. In addition, funding for the Battery Energy Storage Test Facility (BEST) was terminated, and efforts to develop applications of several types of advanced batteries were reduced. 31/ Similarly, budget changes in solar programs also held up appropriations for solar pond activities. 32/ Some ponds have a natural salt concentration which traps heat energy from the sun and stores it at the bottom. Solar pond activities seek ways to use this energy for the production of space heat and electric power.

Several changes may occur at the subprogram levels as a result of the Administration's proposals to cutback funding for FY82. These changes could include termination of thermal storage development for district heating, and cancellation of demonstrations of off-peak electric storage at end-use sites. Demonstrations of underground pumped hydro, compressed air storage, and seasonal aquifer storage could be deleted. Technology development for small-scale superconducting magnetic storage could be ended, and there could be reduced levels of support for battery and fuel cell developments. Also, applied research for near-term batteries for electric vehicles would probably be eliminated, as would research on batteries for

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31/ Ibid, p. 546.

32/ Personal communication, Sam Schweitzer, DOE Solar Thermal Program. Nov. 6, 1981.

photovoltaic and wind energy storage. 33/ In addition, although increased levels of support were authorized for FY82 solar programs to develop solar pond technology, it is not clear whether these increases will survive the appropriations process. 34/

At the hearings, cutbacks in storage program efforts were discussed in terms of the potential for research investment losses and the prospects for increased private sector involvement. Representative Wolpe expressed an interest in being informed about "...facilities where we have a substantial research investments that are being terminated essentially in mid-stream..." 35/ In response to this concern, the witnesses focused their testimony on five project areas: hydrogen, battery storage, underground storage, chemical heat pumps, and storage for district heating.

Dr. Savitz acknowledged that some storage-related R&D work would be ended, and commented on the status of efforts in the areas of hydrogen, battery storage, and underground storage. In regard to hydrogen, she recounted that "...in looking at the priorities and the dollars that were available for the long term work, we felt that the hydrogen work could not be funded at this budget level. We wanted to be able to as completely fund the other programs as possible." 36/

As for battery storage, Dr. Savitz concentrated her testimony on the Battery Energy Storage Test Facility (BEST), which was initiated

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33/ Hearings, p. 552.

34/ Personal communication, Sam Schweitzer.

35/ Hearings, p. 564.

36/ Ibid, p. 542.

by the Energy Research and Development Administration in 1975. After an expenditure of $17 million, the facility was due to begin testing advanced batteries for dispersed applications during 1981. 37/ Dr. Savitz testified that, "One of the [substantial investments] is in [the BEST] facility...we have bought or are installing the lead acid batteries which will be used as sort of the standard batter[ies] for testing new batteries..." 38/ However she indicated that:

> What we will not be able to do is purchase advanced batteries to test...in the facility. That is one of the things we are discussing with EPRI [the Electric Power Research Institute], whether they would be able to put more money into purchasing some of those batteries. The facilities will also be available for the private sector to use on their own. 39/

Dr. Savitz also commented on the impact of budget cuts on efforts to develop underground storage systems. She testified that:

> In the underground energy storage system, there are the areas where we have been which were ready for demonstration and will not be continued, particularly, the aquifer system where we have been drilling for water and then will take the waste heat from a power plant, store it there in the summertime and in the wintertime be able to extract the warm water, use that to heat hospitals or schools. 40/

37/ Electric Power Research Institute. EPRI Journal, v. 6, May 1981. p. 20-21.

38/ Hearings, p. 564.

39/ Ibid.

40/ Ibid, p. 563.

Mr. William F. Thorn commented that his company's involvement in the development of a chemical heat pump may suffer from the Administration's policy changes. He testified that, "Federal funding is vital to sustain the evolution of this important energy-saving technology since the cost attendant to the continued development of the industrial size units is significant." 41/ He pointed out that the investment risks may prohibit the private sector from picking up the development. He emphasized that, "Private funding for this activity is unavailable because there is no industrial operating experience that certifies the chemical heat pump performance predictions, economics and equipment safety." 42/ Furthermore, he observed that, "If Federal funding is unavailable, there is a high probability that development will be terminated due to the risks I previously cited." 43/

Mr. Thorn indicated that another company project may be jeopardized by the shift in Federal policy for energy storage. This project involves the development of a district heating system which would incorporate an energy storage mechanism. According to Mr. Thorn, this system will take reject heat from an aluminum plant, convert it to hot water, and pump the hot water into thermal storage. 44/ He indicated that various thermal energy storage alternatives are being explored to link the constant source of industrial reject heat with the varying community thermal

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41/ Ibid, p. 570.

42/ Ibid, p. 571.

43/ Ibid.

44/ Ibid, p. 586.

demand. 45/ These alternatives include "...both aquifers and an abandoned coal mine in addition to the baseline concept of insulated, above-ground, steel tanks." 46/

PROSPECT FOR INCREASED PRIVATE SECTOR ROLE

The future role expected of the private sector was an important issue raised at the hearings. Mr. Thorn expressed a concern that the Administration's policies of more rapid equipment depreciation, tax credits and fuel price decontrols may not be sufficient to encourage the development and implementation of some advanced storage technologies. He stated that:

> [the current Federal incentives] do not adequately reduce these types of risks and front-end costs at the critical time when the first decision to proceed with a project must be made. Often, a considerable sum of money must be spent in deciding to implement a project and this is only recoverable through incentives if the project is found to be viable and proceeds to implementation. Similarly, few incentives are available to public agencies working to initiate such a project. 47/

However, Dr. Savitz suggested that there are some indications that the private sector would continue or possibly increase its efforts in the battery storage area. She stated that:

> we have had a fair amount of cost-sharing in many of these programs, particularly the near-term battery work, about 30 percent cost-sharing, and it is felt in some of those the private sector would continue to fund th[em], as we dropped our funding. It may be at a lower level because they may just still put in the same amount of money. 48/

45/ Ibid, p. 572.

46/ Ibid.

47/ Ibid, p. 570.

48/ Ibid, p. 542.

Additionally, she pointed out that EPRI could take a more important role in the development of battery storage technology. Dr. Savitz testified that:

> the building of this B[EST] facility has been a 50-50 cost-sharing with us and with EPRI...as our program is changing direction and focus, EPRI might do some of the more near-term things if industry is not going to pick them up...The utility industry has problems in its finances, the amount of money that EPRI gets is decreasing slightly, but their efforts in conservation and energy efficiency have been increasing over the past 2 years, and it has been a very, very good effort across the board in these programs. 49/

ADMINISTRATION'S INITIATIVE TO END STORAGE PROGRAM

In agreement with the House allowance, the Senate Appropriations Committee recommended an appropriation of $40.9 million for the Energy Storage Program during FY82. 50/ However, in September 1981, as part of its continuing effort to curb Federal spending, the Reagan Administration proposed a 12% reduction in funding levels--in addition to the FY82 funding cutbacks that had been incorporated into reconciliation--for Federal programs during FY82. As one consequence of this additional, proposed reduction, the DOE Amended Budget Request for FY82 asked for $11.2 million to terminate immediately the Storage Program. 51/ The proposal

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49/ Ibid, p. 557.

50/ U.S. Congress. Senate. Committee on Appropriations. Energy and Water Development Appropriation Bill, 1982; report pursuant to H.R. 4144, 97th Cong., 1st Sess. Washington, U.S. Govt. Print. Off., 1981. 165 p. (97th Cong., 1st Sess. Senate. Report no. 97256)

51/ U.S. DOE. FY 1982 Budget Amendment to the Congress. Oct. 1981. (Revised Nov. 6, 1981) p. 107-109A.

to end the energy storage program has raised concerns related to both short-term and long-term energy storage activities.

Mr. James Birk, Manager of the Energy Storage Division at the Electric Power Research Institute, has stated that termination of the program would bring almost all energy storage developments to a standstill. 52/ He suggested that approval of the Adminstration's proposal to end the storage program would have several immediate consequences:

(1) Developments in the areas of underground pumped hydro and near-term compressed air storage would likely be taken up by private industry, but these are not the technologies of greatest interest to utilities.

(2) Some feasibility work on magnetic storage would probably continue, but technology development is likely to stop.

(3) Development of thermal storage for residential use would likely continue, but implementation is uncertain and may require Federal incentives.

(4) Activities for both near-term and long-term battery storage are not likely to be picked up by the private sector, and the BEST facility will likely go unused.

52/ Personal Communication, James Birk, Manager, Energy Storage Division, Electric Power Research Institute. Nov. 9, 1981.

IV. SUPPORTING TESTIMONY FOR THE RECORD

Allied Corporation
P. O. Box 9005R
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(201) 455-4513

L. J. Colby, Jr.
Director, Public Policy
Technology

November 20, 1981

Honorable Marilyn L. Bouquard
Chairman, Subcommittee on Energy Research
and Production
Committee on Science and Technology
US House of representatives
B-374 Rayburn House Office Building
Washington, D.C. 20515

Dear Madame Chairman:

I am transmitting a statement on behalf of Allied Corporation and requesting that it be placed in the record for the Subcommittee's December 8, 1981 hearing on energy storage systems.

The attached statement summarizes the ongoing and planned research and development programs at Allied Corporation in the areas of battery systems and electrochemical storage systems. At this point, Allied is not seeking Federal Government funding for any of these systems. Because of cutbacks in the R&D budget for the Department of Energy (DOE), it is anticipated that existing funding for a variety of DOE programs will be cut back further and possibly even terminated. With this in mind, I am recommending that Federal assistance in a non-funding sense could be an important element in the development of future commercial markets for batteries and energy storage systems now in the research phase. An example would be the re-examination of Federal purchasing criteria to determine if new criteria should be developed and initiated to open up Federal markets for new battery and storage systems. Such an action would better define the market potential for various new battery and storage systems and therefore serve as a justification for continuing and possibly expanding corporate R&D spending in these areas.

If you have further questions, please contact Mr. Jerry Halvorsen in the Washington office for Allied Corporate Technology. Mr. Halvorsen can be reached on 659-3673.

Sincerely yours,

SUMMARY STATEMENT ON ALLIED CORPORATION'S BATTERY AND ENERGY STORAGE SYSTEMS

By Dr. L.J. Colby, Jr.
Senior Vice President - Technology
Allied Corporation

BATTERY SYSTEMS

The battery systems group is Allied's largest electrical business. Allied's Eltra Corporation is a major manufacturer of lead acid batteries, with two divisions operating in this area: Prestolite and C&D Batteries. Principal battery research, development and engineering installations are at Toledo, OH (Prestolite Battery); Plymouth Meeting, PA (C&D Batteries); and Morristown, NJ (Corporate Research Laboratory).

Allied's battery group is actively pursuing new battery technology through its R&D programs. The general thrust of the programs has been to improve performance and reliability and to reduce cost. C&D also is positioning itself to take advantage of profitable new opportunities that may emerge in the near future. These include batteries for photovoltaic (solar energy) applications, electric vehicles and electric utility peak shaving/load-leveling applications. In all three areas Allied has embarked upon aggressive R&D programs.

The C&D Batteries Division is the largest industrial battery manufacturer in North America. This market is rapidly approaching a half billion dollars annually, and C&D currently has more than 25 percent of the available sales volume. At present, C&D is the only manufacturer of batteries specifically designed to store energy generated by direct conversion of sunlight to electricity. Although the market for these photovoltaic batteries is relatively modest, it is expected to achieve an annual volume of around $80 million by the early 1990's. In the utility load-leveling area, C&D has delivered batteries to the Battery Energy Storage Test (BEST) facility in Hillsborough, NJ. The two-megawatt-hour installation includes 64 battery modules weighing a total of a quarter of a million pounds and providing the energy output of 5,200 automobile batteries. The BEST facility is a joint effort of government and utilities to test the feasibility of using lead-acid batteries for load-leveling.

The Prestolite Battery Division manufactures a full line of starting batteries for cars, heavy-duty trucks, farm equipment, off-the-road equipment, marine applications, lawn and garden equipment, golf carts and private aircraft. From a technological standpoint, the starting, lighting and ignition battery industry has undergone dramatic changes in the last several years. The most evident change has been the switch to maintenance-free batteries. Most maintenance-

free batteries are designed with a new lead-calcium alloy as a substitute for the conventional lead-antimony construction. Approximately one-third of Prestolite's capacity has been converted to maintenance-free production, and this percentage is scheduled to increase rapidly in the next few years.

The other major change to occur in the industry is the application of expanded metal technology to battery grid production. The expanded metal process forms battery grids by continuously expanding metal from a lead-calcium strip. Prestolite has pioneered the development of these expanded metal grids, which offer lower unit weight, improved product performance, lower capital and production costs and require considerably less floor space for equipment than cast metal grids. The major technological goal within the industry in the past few years has been the development of lighter, smaller, high-power-density batteries with power capacity comparable to those available now. Prestolite is focusing its development efforts on the eventual commercialization of a high-power-density battery.

ELECTROCHEMICAL ENERGY STORAGE SYSTEMS

The major research and development effort at Allied is dedicated to the lead-acid energy storage system. The current R&D program in lead-acid systems is geared to improve performance, extend life and reduce costs in order to remain competitive in current markets and position lead-acid batteries to participate in developing markets. Within Allied, work on the lead-acid system is conducted at three locations: the two operating divisions, C&D Batteries and Prestolite, and also at the Corporate Research Laboratory in Morristown, NJ. The charter of the Corporate Research Laboratory is to develop a better understanding of the fundamental processes, electrochemical, physical and chemical, which govern the functioning of lead-acid batteries. The two manufacturing divisions also perform selected basic research projects, but in addition, they must confront customer concerns, product extension and process improvement needs. The divisions focus on basic and applied R&D on product and process improvements for new and existing markets. In addition, technical and engineering support is supplied to existing products and processes.

In recognition of changing and emerging market needs, competing technologies, growing environmental concerns and dwindling natural resources, Allied supports work in energy storage areas other than lead acid. These include near term, advanced and exploratory electrochemical energy storage systems. The bulk of this future-oriented effort is performed at the Corporate level, although some program segments will be conducted at the appropriate division. Work on these non-commercial systems is generally narrower in scope than lead-acid investigations. While attention is focused on engineering concerns, the bulk of the effort is fundamental research.

Generically, these non lead-acid programs include alkaline battery systems (e.g. nickel-iron, nickel-zinc and nickel hydrogen), elevated

temperature systems (e.g. sodium-sulfur and lithium-metal sulfide) and halogen systems (e.g. zinc-chlorine and zinc-bromide). These systems are properly classified as high risk from technological, economic and market development standpoints. Technically, the identified problems are of a fundamental nature and may be unresolvable in the near term, with commercialization in most cases being 5-25 years off. In addition, capital requirements to achieve commercialization will be significant as will be the research and development work necessary to surmount the technical challenges and reduce the concept to a practical product. The nearterm and advanced electrochemical storage systems being developed at Allied are aimed initially at markets that are small, poorly defined or nonexistent, including load leveling, photovoltaic and electric vehicles. For most of the systems, market acceptance will be slow because of the intrinsic characteristics of the electrochemical reactions and the design necessary to accommodate these reactions, i.e., high temperature operation, visible ancillary support systems, perceived dangerous components, etc.

Beyond the advanced electrochemical systems are concepts of future promise. For Allied Corporation, the principal entrant in this exploratory field is the recently announced Conductive Polymer Battery, which will be the prototype for a new class of electrochemical storage systems that do not rely on the conductivity of metals as an integral part of their operating cycle. This battery uses organic polymers which, when suitably treated, develop a set of controlled electrical properties. More specifically, their electrical conductivity can be varied from insulator through semiconductor to metal. These materials can serve not only as an active material in battery electrodes, but also as the mechanical support and current collection system for the components. This duality promises lighter, compact, high performance batteries with long cycle life, low cost and heretofore unachievable design flexibility. This program, which Allied has pursued without external funding for several years is scheduled to enter a new phase of activity during 1982/83. The project will be expanded from a research activity to include practical battery considerations, such as design, packaging, engineering, manufacturing and practical economics. The intent is to compress the time necessary to commercialize the product by performing a concurrent, instead of sequential development program.

AMERICAN ELECTRIC POWER *Service Corporation*

AEP

180 East Broad Street, Columbus, Ohio 43215
(614) 223-1000

DORMAN M. MILLER
Vice President
Customer Services
(614) 223-1370

November 5, 1981

The Honorable Ron Williams
The United States House
of Representatives
Subcommittee for Energy
Research and Production
Rayburn Building, Suite B374
Washington, D. C. 20515

Dear Mr. Williams:

It has come to my attention that there is a hearing which is scheduled for November 17-18, 1981 to consider the future funding for electric storage programs of all types.

We have a concern that certain programs which are currently underway under the auspices of the Oak Ridge National Laboratory could be terminated. We recognize that there is a large number of different kinds of storage systems, but the customers served by the American Electric Power System have the opportunity to install thermal storage equipment in their homes and businesses which has been introduced into this country by our company and for which substantial additional research needs to be continued.

I enclose for your review a brochure which described a typical thermal storage furnace and a room unit. The two principal items of cost in the construction of this equipment are the very special olivene-based bricks and the high-quality insulation. Currently, the cost of these two items are such that it is difficult for the American consumer to elect to purchase this equipment as compared with other devices.

It is important that the electric generation capacity now available in the electric systems of this country be preserved for as long a period as possible because of the ever-rising power plant construction costs, which must be passed on to the customer in the form of increased rates.

The important contribution which thermal storage can make to the preservation of existing generating capacity is that the equipment operates totally off-peak, that is to say, on our System from 11:00 P. M. to 7:00 A. M., at which time it stores heat energy which can then be used through the on-peak hours of the day which are 7:00 A. M. to 11:00 P. M., for the comfort conditioning of the home. It is a system which is responsive to off-peak rate structures that contribute to our country's need to preserve existing electric generating capacity.

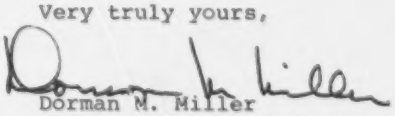
If the customer elects the option of heating the home with straight electric resistance or with a conventional heat pump, future capacity requirements will increase because they make little contribution toward the preservation of our existing capacity. But the economic circumstances today are such that the customer is not concerned, much less aware, of the future cost of providing generation capacity, but rather is looking at today's cost for the equipment and its operating cost, as compared with other alternative systems.

Thermal storage equipment costs more than the other options, but this need not be a continuing circumstance. With the improvement in the design and manufacture of the expensive storage bricks, as well as the insulation, substantial reductions in cost can be effected.

Some of the research which has just recently begun and which has been funded by Oak Ridge National Laboratory, offers the possibility of effecting this very important cost reduction. These costs can be reduced through original research and perhaps long-term research. The American consumer will be the principal beneficiary of future important cost savings.

I trust that the need for continued research investment will be given full recognition as this committee of Congress makes it deliberations.

Very truly yours,



Dorman M. Miller
Vice President, Customer Services

DMM/jg
Enclosure

AMERICAN PUBLIC POWER ASSOCIATION

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Athens, Tennessee
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Harlan, Iowa
WILLIAM C. WALBRIDGE
Sacramento Municipal Utility District
Sacramento, California
ROBERT C. YOUNG
Burlington, Vermont

December 8, 1981

The Honorable Marilyn L. Bouquard
Chairman
Energy Research and Production
Subcommittee
Science and Technology Committee
United States House of
Representatives
B-374 Rayburn House Office Building
Washington, D.C. 20515

Dear Madam Chairman:

Please find attached three copies of comments by the American Public Power Association addressing the need for the Energy Storage and Electrical Energy Systems programs of the Department of Energy. This material is submitted to be included in the record for the hearing held by your Subcommittee on December 8, 1981.

If you or your staff have any questions or comments on this statement, please contact me at the address or phone number noted above.

Sincerely,

R. Eric Leber
Director of Energy Research

REL:jac

Encl.

Comments of the
AMERICAN PUBLIC POWER ASSOCIATION
on
ENERGY STORAGE AND ELECTRICAL ENERGY SYSTEMS
Submitted to the
House Science and Technology Committee
Energy Research and Production Subcommittee
by
R. Eric Leber, Director of Energy Research
December 8, 1981

The American Public Power Association submits the following statement in support of a responsible federal program in research, development, and demonstration for a strong and safe electric energy transmission, distribution, and storage network.

APPA is the national trade association of 1,750 locally owned electric utilities in 48 states, Puerto Rico, the Virgin Islands, Guam, and American Samoa. Virtually all APPA member utilities operate transmission or distribution systems, or both, and two-thirds of the membership are exclusively power distributors. Local public utility systems manage transmission and distribution plant valued at approximately $20 billion with additional investments made annually in the range of $1.5-$2.0 billion. Thus, their interest in the integrity and safety of electric energy systems is substantial.

Electricity is playing an increasingly important role in the U.S.

- Electricity use is growing (2.5% to 5.2%/year) at more than twice the rate of overall energy use (1.1% to 2.5%/year).
- Over the next two decades, electricity will account for about half the energy we use, up from 30% today.
- Major sectors of our society have been shifting their energy use from non-electric resources into electricity. Compared to 1973, the residential, commercial, and industrial sectors consume about 25% more electricity but 5%-10% less non-electric energy (oil, gas, coal, etc.).

- The average worker requires nearly five times as much electricity to remain fully productive today, as contrasted to thirty years ago.
- Though the average annual rate of growth in the use of primary energy is now less than that of the gross national product, electricity use is increasing at roughly 1.5 times GNP.

But the adequacy of electric supply for the late 1980s and beyond is in question.

- More than 25% of the coal and nuclear power plants scheduled to come on line before 1985 have either been rescheduled for service beyond 1989, postponed indefinitely, or cancelled.
- Reserve margins are expected to decline, which may adversely affect electric system reliability, particularly in regions subject to fuel-supply interruption.

Greater emphasis will be placed on the nation's transmission and distribution grid as a means of providing needed electrical energy.

Meeting demands for electricity over the coming decades will require more inter-regional transfers, more local "power pooling," interconnection of dispersed generators and storage systems, and enhanced communications between utilities and with consumers. It is most important—on social, economic, and strategic grounds—that these exchanges be conducted safely, efficiently, and reliably.

Through a sustained research, development, and demonstration program we can help avoid overstressing the electrical system (that is, minimize losses—line losses, core losses, corona losses, stray currents, etc.—that dissipate about two quadrillion Btu a year; structural problems of ice loading and aeolian vibration; crazing, cracking, treeing, tracking, and corrosion; frequency and voltage instability, etc., etc.) while improving the quality of service to the U.S. consumer (through more stabilized costs, negligible bioelectromagnetic

effects, reduced noise and other environmental/aesthetic improvements, clean and efficient transportation systems, availability of off-peak energy through storage, hardening the grid against adverse electromagnetic impulses, better motors, high capacity communications for energy management and monitoring and for interface with non-utility generating/end-use equipment, etc.).*

The electric utilities are willing to pursue new technologies, to try unconventional energy approaches (see the attached copy of the "Public Power Innovation" list), but they have neither the resources nor the time to go it alone in R,D&D. The non-federal sector spends about $30 million a year on energy storage research and development and a comparable amount for electric energy systems. It is proposed that the Department of Energy's budget for these two areas be established at approximate parity with these non-federal spending levels.

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*Other countries are acutely aware of the benefits of R,D&D and the costs of extended outage. Nearly half of some key (high-voltage) equipment used by U.S. utilities is now being purchased abroad. Regarding national security, a lesson can be taken from the U.S.S.R., where networking is provided on a widespread basis for more reliable service.

Electricity consumers in the Soviet Union are in one of three categories:
1. Those for whom continuous supply is necessary (hospitals, some public buildings, military bases, etc.);
2. Those who can be interrupted for 15-20 minutes at a time; and
3. Those who can be interrupted for several hours.

Redundant service networks (i.e., supply from independent power plants through independent substations and T&D lines) are used for the first and second categories, however, automatic activation of emergency backup systems is not provided in the latter case. For high-priority users, the phases are physically separated to reduce the probability of damage due to migrating faults, flashover, or external effects. Farms and agricultural facilities are in the third category—having a single source of electricity—but they are presently being upgraded to second category service.

Several publications (among them Public Power magazine) discussing the related question of U.S. vulnerability have become available in recent years.

load management

PALO ALTO, CAL., is investigating the prospects for automatic load management in its service area. Frank Betley, 415/329-2297.

FORT COLLINS, COLO., has initiated residential demand rates, and subsequent workshops for all-electric customers highlight the advantages of the rate and voluntary customer-initiated load management techniques. Judy Putnam, 303/221-0501.

NEBRASKA PUBLIC POWER DISTRICT, Columbus, Neb., has instituted an off-peak time clock rate for irrigation systems in its service area and is also testing hardware for the direct control of water heaters, air conditioners and electric heating. NPPD has tested the air conditioning demand reduction and conservation potential of additional insulation and power roof ventilators, as well as the addition of an air conditioning heat recovery unit. Also, water heaters have been monitored to understand their impact on load profile. NPPD conducts an off-peak load-building and energy conservation promotion through the use of seasonal "Tailgate" signs on its vehicles throughout the state. NPPD also provides text, artwork and a showing schedule to cable TV systems around

ANAHEIM, CAL., has an incentive program to encourage its customers to install timing devices on their swimming pool circulating pumps. Gordon Hoyt, 714/533-5401.

GREENVILLE, N.C., has expressed interest in exploring management techniques for residential and commercial load control. Charles O. H. Horne Jr., 919/752-7166.

SACRAMENTO, CAL., has instituted several load management programs including time-of-day rates, attitude surveys on load management, and residential, commercial and industrial air-conditioner control. About 300 homes in Sacramento are equipped with radio-controlled air conditioners. William Walbridge, 916/452-3211.

MUNICIPAL ELECTRIC AUTHORITY OF GEORGIA (MEAG), Atlanta, Ga., has several members involved in load management. The FORT VALLEY UTILITIES COMMISSION is spending about $140,000 to install ripple control devices to help its customers curb future electric costs. Harwell Sutton, 912/896-3601.

LAWRENCEVILLE, GA., controls about 1,000 air conditioners through its central Motorola management system. Don Martin, 404/963-9834. Other MEAG cities with similar load management programs are East Point, College Park, Thomasville, Fitzgerald and Washington. Donald Stokley, 404/659-1555.

GRIFFIN, GA., has installed automatic switches on 1,600 air-conditioners in the hope of achieving significant economic savings. Clifford Hutson, 404/227-2213.

OMAHA PUBLIC POWER DISTRICT, OMAHA, NEB., is evaluating various load management options for its service area. Lloyd Shalla, 402/536-4000.

GAINESVILLE, FLA., has been supporting a load management study of its system. A portion of this effort focuses on policy for energy conservation within the operations of the local government. Ed Regan, 904/374-2833.

GRAND RIVER DAM AUTHORITY, VINITA, OKLA., is looking into the impact of time-of-day pricing on its load profile. Dale Symms, 918/256-5545.

CONWAY, ARK., is continuing in a central air conditioning load control program that was started back in 1978. Under this program the utility will enter into a contract with the consumer to install a radio-controlled switch on any air conditioners rated three kva or larger. Presently, 920 of these switches, representing a total load of 4,900 kva, have been installed. Additionally, 201 switches, representing 2,235 kva of load, have been installed on commercial and industrial air conditioning units. Residential customers are given a credit during the months of June, July and August of $1.45 per kva of air conditioning load controlled up to a maximum of 20 percent of a total bill. The credit for commercial customers during the same period is 92 cents per kva of controlled air conditioning load up to a maximum of 20 percent of their bill. Roger Mills, 501/329-5641.

NORTH LITTLE ROCK, ARK., has more than 2,000 radio-controlled switches on customers' air-conditioners. It is conservatively estimated that these load management devices represent a reduction of about 2,000 kw (or 1.25 percent) in the peak demand. Robert Hogan, 501/373-0100.

COLORADO SPRINGS, COLO., is involved in a study of residential and commercial load management options. James D. Phillips, 303/471-6201.

NORTH ATTLEBOROUGH, MASS., has thermal storage systems in its nursing home as well as its town hall. Furthermore, it has provided radio controls for consumers' water heaters. Harold Payne, 617/699-7541.

LINCOLN, NEB., is investigating potential for load and peak demand control through rates, load management and legislation. Terry Bundy, 402/475-4211.

BURBANK, CAL., with support from the APPA research program, is in the initial phases of a city-wide industrial load management control system. Results from a local aircraft parts manufacturing facility indicate that energy savings in the range of 5 to 10 percent can be expected from industrial load management. Acey Floyd, 213/847-9640.

have been instituted at Sacramento offices, where office hours run from 7:30 a.m. to 4:30 p.m. in order to reduce late afternoon and early evening peak demands. William Walbridge, 916/452-3211.

NORRIS PUBLIC POWER DISTRICT, BEATRICE, NEB., installed a load control system on 16 electric heating units in the high school and six in the elementary building of the Norris-Hickman School, which has the capacity to shed loads as the demand on the system reaches a pre-set level. Glen Schmieding, 402/223-4038.

LOS ANGELES, CAL., has implemented a system-wide swimming pool pump timer reset program involving the resetting of residential pool pump timers to off-peak operation, with reduced operating hours. More than 70,000 pool owners will be reached by the program in 1981. Melvin Frankel, 213/481-4104.

LOS ANGELES In testing radio-controlled time-of-use meters in homes under a two-year test. The voluntary program will involve tests on air conditioners and time-of-use meters. Incentive payments will be made to customers who participate. Robert Pettinato, 213/481-4211.

MARSHALL, MINN., has implemented a 900-point load management program at a cost of $165 per point, which has cut 4 percent off its 26-mw peak, a savings of $60,000 last year. F.A. Rome, 507/532-2213.

FAIRMONT, MINN., has installed load management equipment on 939 air conditioning units and 443 water heaters, at an approximate cost of $182 per point. This represents a total 8 mw under control (6.2 mw of air conditioning and 1.9 mw of water heaters). Kevin DeVillers, 507/235-6691.

DENTON, TEXAS, is involved in a $350,000 effort to design and install 100 to 150 meters for remote two-way communications, meter reading, and eventually load management via cable TV lines. Bob Nelson, 817/566-8230.

BEATRICE, NEB., has an electric alert system that automatically informs customers by local radio of high demand on system and requests voluntary cutbacks on energy during peak periods. James Bauer, 402/223-5211.

YORK COUNTY RURAL PUBLIC POWER DISTRICT, YORK, NEB., is controlling the demand at local irrigation wells in order to minimize the on-peak load. Hilary Neesen, 402/362-3355.

SALT RIVER PROJECT, PHOENIX, ARIZ., has budgeted $500,000 for a demonstration of a 200-meter, two-way load management system at its Ahwatukee substation. This experiment will allow SRP to evaluate the range of load management functions available, gain data to respond to the Public Utility Regulatory Policies Act and gain staff and consumer experience with the equipment. SRP is continuing its interest in implementing site-controlled load management programs through use of residential demand limiters. Additionally, it has implemented time-of-use rates based on a survey of 28,000 consumers to determine their acceptance of time-of-use energy and load management programs. Furthermore, with partial funding from APPA, the Salt River Project has developed a computer model that aids utilities in forecasting future demands for electricity. R.M. Hayslip, 602/273-2896.

the state which run peak reduction and energy conservation messages on their scanner or message boards as a public service. Byrle Gross, 402/563-5539.*

OSAGE, IOWA, has initiated a load management program to minimize peaking requirements at 700 locations—half air conditioners and half water heaters. Weston D. Birdsall, 515/732-3731.*

ATHENS, TENN., is hosting a DOE/TVA/Athens project to demonstrate advantages or disadvantages of combining all known load management and system automation techniques into an operating utility. There will also be some added features such as photovoltaics, congeneration and heat storage in an attempt to accumulate the best state-of-the-art electric innovation into one operating utility. George Usry, 615/745-4501.

ALBANY, GA., has found the cost of a hybrid radio/carrier signaling system for direct load control to be lower than that of an all-radio system, which sends load-shedding signals to receivers mounted at each customer's appliance. The radio systems require a receiver and a switch at each appliance while the hybrid system needs only one receiver for a number of switches. Also, the cost of having utility crews work overtime to install the switches proved to be between $1.50 and $6.50 per switch cheaper than using private contractors. Walter Rodemann, 912/883-8330.

PHILIPPI, W.VA., is testing the Metretek system for load management and automatic meter reading in order to improve employee productivity and the average daily load factor. Philippi will also test other functions of the Metretek network for DOE, EPRI and APPA, including load management of space and water heaters and time-of-day, demand and simultaneous water and electric remote metering. Joseph Mattaliano, 304/457-3701.

MEMPHIS, TENN., with TVA, is implementing a voluntary program called "Cycle and Save," designed to interrupt operation of an air conditioner and/or water heater during times of high electrical demand through use of a radio signal. Bill Lagrone, 901/528-4141.

MARBLEHEAD, MASS., has a "Stop Peaking Campaign." Through a series of "chain" telephone calls, radio broadcasts, and transmissions via police department radio, residents are asked to cut back on electrical usage. The campaign includes local students and a contest for elementary students to think up ideas for saving energy. Richard Bailey, 617/631-0240.

GREENVILLE, N.C., has had a "Beat the Peak" load management program in operation since 1978. The program was expanded in 1980 to include more than 4,400 air conditioning switches and more than 4,600 water heater switches. Public acceptance of the program has been tremendous. Charles Horne Jr. 919/752-7166.

SACRAMENTO, CAL., has a contest for residential customers who help cut summer peak loads. Those who can reduce energy consumption by a specified amount qualify for a chance in the contest. Prizes provided by Sacramento include microwave ovens and energy-efficient fluorescent lamps. Efforts to reduce summer peaks

energy storage

TENNESSEE VALLEY AUTHORITY is installing ceramic brick units in some 75 residences in a heat-storage demonstration project to provide space heating from off-peak electricity. This program is a means of reaching low-income customers that have so far failed to take advantage of other energy conservation measures offered by TVA. The heat-storage unit installations are comparable standard baseboard heating units normally used by the occupants. John Melton, 615/632-6750.

MARTINSVILLE, VA., with the help of APPA and scientists at the Research Triangle Institute in North Carolina, is assessing dispersed electric energy storage options (primarily advanced batteries and the REDOX system developed by NASA) for municipal utility systems. Bob Corekin, 703/638-3971.

NORTH ATTLEBOROUGH, MASS., with APPA partial funding, is demonstrating dispersed phase-change thermal storage. Eric Leber (APPA), 202/775-8300.

PROVO, UTAH, with a grant from APPA, is assessing the potential for the use of hydrogen in fuel and energy storage applications in municipal utilities. George Morse, 801/373-7170.

ATHENS, TENN., in conjunction with TVA, has a program to install 17 heat storage units including a 120-gallon storage water heater. Athens has installed 12 brick storage units, three water storage units and two eutectic salt units. George Usry, 615/745-4501.

HIBBING, MINN., plans a 5- to 15-mw pumped storage demonstration project which will use relatively small water impoundments created during local mining operations of the Messabi Range. By using existing water-filled excavations, construction costs can be reduced significantly. The purpose of the project is to generate sufficient electric power locally to meet peak load demands. Joseph Vumbaco, 218/263-7515.

HARLAN, IOWA, is discussing with the National Aeronautics and Space Administration (NASA) Lewis Laboratories the prospect for near-term chemical energy storage via the REDOX approach. Allen Burchett, 712/755-5182.

SALT RIVER PROJECT, Phoenix, Ariz., is aggressively involved in the demonstration of residential and commercial ice storage units. To date, five cold storage tanks have been installed and a program initiated to determine the impact of cold storage on energy-use patterns. Jim Grady, 602/273-5578.

BRIEFING ON DOE ENERGY STORAGE PROGRAMS

Presented to

Mr. Ronald E. Williams, Staff Aid
House Science and Technology Committee

Presented by

Dr. Paul A. Nelson, Director
Electrochemical Technology Program

and

Dr. John J. Roberts
Associate Laboratory Director
Energy and Environmental Technology

November 20, 1981

11/10/81

IN SUPPORT OF DOE ENERGY STORAGE PROGRAMS

P. A. Nelson
Argonne National Laboratory

Program Objectives

Research and development are underway, sponsored by the Department of Energy, to develop energy storage devices that would enhance the use of coal, nuclear and renewable energy resources in place of petroleum. These devices include development of advanced batteries for electric vehicles, including the following battery systems: lithium/iron sulfide, sodium-sulfur, zinc-chlorine, zinc-bromine, metal-air, and fuel cells for vehicles. Batteries are also being developed for load leveling for electric utility systems to improve the load factor on nuclear- and coal-fired generating plants. Similar batteries would also be appropriate for use in solar and wind energy applications. Technology base research is also underway on new electrochemical systems and DOE is the major source of funding in the U.S. for this base technology effort. Other devices under development include flywheel rotor technology for load, vehicle, and stationary energy storage. Thermal storage techniques are being developed, involving phase change materials for building heating and cooling and seasonal storage methods are being studied. Also, chemical heat pump technology is under development for heating and cooling of buildings, and electrochemical methods for producing hydrogen, an alternative fuel, are under study.

Background

Government efforts under this program began in about 1970 under the Atomic Energy Commission, Division of Applied Technology, with the initiation of a program on development of batteries for storing energy in electric utility systems and development of hydrogen storage devices. At that time, only a few minor programs were underway in industry and universities on advanced batteries. The increase of funding by the government in the energy storage area resulted in the U.S. achieving a position of worldwide leadership in the development of energy storage devices, even though the funding levels have been moderate (30 to 50 million dollars per year) as compared to other energy programs.

Justification for Continuing Programs

The main problem in development of electric vehicles is the shortcomings of presently available batteries. Similarly, energy storage for load-leveling for

electric utilities and for solar and wind energy applications also will require development of batteries or other devices not now available.

For both of these market sectors, the batteries or other devices require such a long time for development that private industry cannot completely fund the early stages of research and development; these require support from government.

The transportation sector uses 52% of the oil consumed in the United States and more than the total amount imported. High oil demand contributes to higher oil prices, especially under OPEC's cartel pricing. There is an additional cost, in that military expenditures are required to protect the oil fields in small foreign states. It is estimated that a reduction in our dependence on foreign oil would have a social value of about $15 to $30 per barrel.

Electric vehicles and other alternatives to vehicles powered by oil-derived fuels should be developed and tested in the market place. The improvements most needed in the battery for a significant penetration of the vehicle market (greater than 500,000 vehicles per year) are increased cycle life and reduction in weight. The latter improvement would decrease vehicle weight and as a result reduce the cost of the motor, controller, and the balance of the vehicle. Electric cars will have limited market potential until the price of gasoline reaches $2.00 per gallon and the cost of an electric car is no more than $1500 greater than that of a gasoline car (1981 dollars). Based on current technology, the price for a mass-produced electric car with a 75-mile range would be $3000 to $5000 more than that of a gasoline car. A limited number of such vehicles will be marketed and, thus, provide an opportunity to improve components such as motors and controllers. However, a major penetration of the vehicle market will require much improved batteries.

Batteries or other storage devices that have long life and low cost would have a beneficial impact on the national energy situation. Such devices are needed for load leveling for electric utilities to improve the load factor on nuclear- and coal-fired generating plants, and for storage of energy in solar and wind energy applications. The problems in developing such batteries are similar to those for electric vehicle batteries, in that both high performance

and low cost are required. For stationary energy storage, very high reliability and a life of 10 years or more are required at a price that is no more than that of lead-acid batteries and, preferably, 25% less. Thus, a variety of systems have been under consideration, including advanced batteries, flywheels, and underground compressed air and pumped storage units.

In addition to the above programs, technology research of a more basic nature has been under way on new electrochemical systems that show promise for electric vehicle and stationary energy storage batteries. From these long-range projects, which have been carried out at universities, national laboratories, and a few industrial laboratories, it is expected that major new battery systems will eventually evolve. This is the type of research that may result in exciting breakthroughs for the next generation and is especially appropriate for government funding.

The costs of the long-range research and development for advanced batteries and other storage devices will require a moderate level of support by the government over an extended period. Industry can share some of the research costs and shoulder all of the cost of developing manufacturing procedures when research and and development has proceeded to a more advanced stage and the prospects for profit are better defined.

November 1981

THE NEED FOR PUBLIC SUPPORT OF R&D

J. G. Asbury
Argonne National Laboratory

Introduction

Broadly conceived, research and development may be defined as activities directed toward the discovery and organization of new information about the nature of physical, life, and social processes and the application of this information in new technology to serve the needs of man. In the United States, as in all of the advanced market economies, R&D is supported by both private and public funds and is conducted by virtually all forms of institutional establishments, including private firms, university departments, and publicly owned/operated laboratories. Because R&D is increasingly perceived as the engine of technological progress and an essential ingredient in economic growth and market competitiveness, the advanced economies have been allocating increasing shares of their domestic products to R&D activities.

The Need for Publicly Supported R&D

Whether supported by public or private funds, research and development is properly conceived as an investment activity with returns and costs subject to the same evaluation principles as other investments. Thus, despite the special difficulties inherent in estimating the returns on most R&D projects, the private firm can be expected to adopt efficient decision-making practices and to carry out its R&D activities to the point where its expected marginal return equals its marginal cost. Depending on its own estimates of relative costs, the firm may elect to conduct a particular R&D project in-house or to enter into a contract with a university, a non-profit institution, or even another firm. Except for the presence of two widely recognized "market imperfections," this investment process, carried out in a normal market environment, could be expected to produce an efficient allocation of resources to R&D activity.

One of the imperfections concerns the discount rate applied by the private firm in calculating the value of future returns. The private discount rate, mainly because of the taxation of corporate profits (before their distribution to shareholders where they are taxed again), is generally regarded as higher than appropriate for society at large, so that the private firm will undervalue future benefits relative to their value to the economy. Although this problem is sometimes used as an argument in favor of public funding to supplement private effort,

it has been pointed out that direct public support may entail its own substantial costs. Discouragement of private sector investment, the substitution of less able public R&D managers for private managers, and less efficient technology transfer are problems that have often been cited. Moreover, the problem of a high discount rate may be alleviated by an R&D tax credit designed to offset part, or possibly all, of the distortions caused by the present corporate tax structure.

The second major cause of underinvestment by the private sector stems from the very nature of the benefits themselves and is not readily amenable to simple institutional or tax remedy. The problem derives from the inability of the private firm to capture, or otherwise appropriate, the full social benefits of R&D accomplishment. For example, only a fraction of the ultimate social gains from a "breakthrough discovery" in the basic sciences or in development of an outstanding new product can possibly be captured by the private firm or the individual making the discovery. Before the firm that has developed a new product has recovered the costs of R&D, competitors may copy or even improve the product. The diversity of production facilities and product characteristics that result would be beneficial to society, but detrimental to the original developer. Although the United States and the other market economies have well developed patent systems to protect the rewards of innovation from appropriation by others, the patent system fails to ensure the complete appropriation of benefits by the developer, even as applied to relatively near-term technology. Although tighter patent systems might be conceived, the costs of interpreting, implementing, and complying with such systems might soon become greater than the benefits of the added incentives they are designed to provide.

Especially in the areas of basic research and high-risk long-term R&D, it is difficult to conceive of government actions, other than direct support of the research itself, that would elicit the desired response by the private sector. Tax credit and other incentive programs can induce greater private R&D expenditures, generally; however, they are likely to fail in the areas of long-range projects. Individual firms, confronted with the inherent difficulty in appropriating the benefits of fundamental research would continue to favor projects designed to assist nearer-term, more appropriable, product development and improvement. Thus, were government, through suitably designed incentive programs, able to bring the <u>overall level</u> of R&D effort up to the socially optimal level,

the distribution of effort between near-term product development and long-range R&D would remain suboptimal.

A corollary to the problem of capture of the commercial benefits of R&D in the market place is the problem of lack of incentive due to the absence of a private market for these benefits. Thus, for example, research to gether new data and information about the response of plants, animals, and man to environmental pollutants would be under-funded because of the absence of a private market for this information. Although such information is clearly essential to the design of socially efficient pollution control regulation, in the absence of government willingness to pay for the necessary research, very little such research would in practice be carried out. Another area where the benefits of R&D are external to the operation of the private market is military technology. Here, again, direct public support is needed to call forth the necessary resources.

It is precisely in the areas of basic research and information about external effects (whether through basic or applied research) that the market economies have found the need for public support of R&D to be greatest.

REPLY NUMBER: GRM-81-068

Ceramatec, Inc.
•HIGH TECHNOLOGY CERAMICS•

December 4, 1981

The Honorable
Mrs. Marilyn L. Bouguard
Chairman of Subcommittee
of Energy Research & Production
Committee on Science & Technology
United States House of Representatives
B374 Rayburn Bldg.
Washington, D. C. 20515

Dear Madam Chairman:

Enclosed is an important but brief position paper prepared by Ceramatec, Inc. which describes the need (and reasons for need) of continued funding for research and development of advanced sodium-sulfur batteries. This position paper is submitted to you as additional information to that which, I understand, you and your subcommittee are attempting to gather in the December 8, 1981 hearing on Energy Storage.

By way of introduction, Ceramatec, Inc. is a small business engaging in high technology ceramics research, development and production. Ceramatec's relation to the sodium-sulfur battery development arises from its position as a prime developer and supplier of essential ceramic components for battery cells. I believe that Ceramatec, because of this role, is in a position of being a reliable source of information regarding the nature of this battery system.

Also enclosed is a brief sketch of Ceramatec, Inc. which details the nature of the company, its interests and accomplishments.

I will be more than happy to answer questions regarding this matter.

Sincerely,

Gerald R Miller

Gerald R. Miller
Vice-President

GRM/jd.

cc: R. S. Gordon, President, Ceramatec

Enclosure

A POSITION PAPER FAVORING CONTINUED FUNDING FOR RESEARCH AND DEVELOPMENT OF ADVANCED SODIUM-SULFUR BATTERIES.

Prepared by

CERAMATEC, INC.
163 West 1700 South
Salt Lake City, UT 84115

for the Hearing on Energy Storage
conducted by

THE UNITED STATES HOUSE OF REPRESENTATIVES

8 December 1981
Washington, D.C.

It is the intent of these remarks to aprise members of the United States House of Representatives of the need to continue and expand funding of a most promising technological system for energy storage - the sodium-sulfur battery (sometimes called the "beta"-battery). Sodium-sulfur batteries have the potential to aid in a major way in decreasing United States dependence on petroleum. In particular sodium-sulfur batteries will ultimately result in the achievement of high performance, long life, cost effective electric vehicles. Recent developments in the development of the technology give credence to the fact that this view can indeed be made into a reality. Especially exciting are developments relating to rapid recharge of battery cells in fractions of an hour and the high performance of battery cells under pulse loading as would be experienced in vehicle acceleration. These new developments, along with previously known economic and technical potentials of the sodium-sulfur battery system (on the attached summary sheet) are being discovered just as the funds needed for further research and development are in jeopardy.

Several key milestones must still be met before the sodium-sulfur battery achieves commercial status and include research on materials and compounds for individual cells as well as systems research efforts in areas such as (1) interconnection problems, (2) safety regulations and (3) materials for battery designs, among others. Government support is vital to a timely penetration of sodium-sulfur powered vehicles into the transportation system (as well as for sodium-sulfur batteries for various stationary energy storage applications). Without increased funding, meaningful fleet tests of sodium - sulfur powered vehicles may be delayed by as much as 10 years with a corresponding delay in the country's ability to withstand a critical petroleum shortage and corresponding skyrocketing gasoline prices. A corollary impact of inadequate funding relates to the rapid progress in sodium-sulfur battery development (a U. S. invention) being achieved in the countries of Japan, Germany, and Great Britain. Through an inadequate rate of sodium-sulfur development in this country we risk substitution of dependency upon petroleum with dependency upon foreign battery technology.

Specific recommendations for maintaining a vigorous sodium-sulfur battery development are:

- Maximimize funding rates for general research to at least a level of $6 million/year.
- Dedicate an additional $5 million/year to electric vehicle sodium-sulfur battery systems research and development.

The development of the sodium-sulfur battery is progressing rapidly worldwide. Significant technical and cost issues must be addressed and solutions demonstrated before a commercially viable product emerges. Government support for research and development to identify these solutions and prove feasibility is required in order that the private sector be able to move quickly and with reasonable confidence toward production and commercialization of this exciting energy storage system.

SUMMARY

SODIUM-SULFUR RECHARGEABLE ENERGY STORAGE BATTERY

Applications

+Electric vehicles (150-200 mile range, rapid 14 second acceleration to 50 mph)
+Energy storage batteries for electric utilities - reduce fossil fuel consumption
+Space and military energy storage systems (e.g., submarines, satellites)

Advantages of the System

+Innovative battery design - liquid electrodes and solid (ceramic) electrolyte
+Use of abundant, low-cost materials (sodium, sulfur, aluminum oxide)
+High battery power and energy to weight ratios
+Energy density over a factor of six larger than conventional lead acid batteries
+Long useful life - no mechanical breakdown of electrodes on repeating charging and discharging
+Outstanding design flexibility to satisfy many requirements
+Completely sealed system - no evolution of gases
+Rapid recharge
+High performance in rapid discharge

Perceived Problem areas. Requiring Research and Development

+Materials research for corrosive environments
+Thermal management for this high temperature battery
+Safety enhancement (public perception of safety as a very important object in any new technology)

Economic Problem Areas

+Expensive and long development programs for electric vehicle and stationary energy storage applications
+Conservative U.S. industry unwilling or unable to invest in expensive, high risk technologies.

GENERAL ELECTRIC COMPANY
STATEMENT OF ADVANCED
BATTERY DEVELOPMENT FOR THE
UNITED STATES HOUSE OF REPRESENTATIVES
HEARING ON ENERGY STORAGE AND
ELECTRIC ENERGY SYSTEMS PROGRAMS

DECEMBER 8, 1981

Since the mid 1960's the General Electric Company has been engaged in a major research and development program on sodium-sulfur batteries. This battery system is now known as the beta battery.

The beta battery has a theoretical energy storage capacity about five times greater than the familiar lead acid vehicle battery, i.e., 760 watt hours per kilogram for a beta battery vs 170 watt hours per kilogram for the lead acid battery. It is constructed of common materials that are inexpensive and available in large quantities. The estimated selling price for large battery systems to provide load leveling for an electric utility system is estimated to be $300 to $500 per kilowatt of installed battery capacity when the battery is successfully developed and produced in large volumes.

General Electric has been investing its own resources developing the beta battery since 1967, and has been receiving major support under contract to the Electric Power Research Institute for 8 years to develop the beta battery for electric utility load-leveling application.

General Electric and Chloride Silent Power, Limited of Runcorn, England, entered into a joint development agreement in 1981. Under this agreement the two organizations are applying their knowledge and capabilities in beta batteries to expedite the development of this technology.

The General Electric-Chloride Silent Power effort has been directed to the development of a highly reliable, long life cell for the beta battery. Once the problems associated with cell development are solved the results will be equally applicable to both utility energy storage batteries and batteries for electric vehicle applications.

The technical requirements for the utility battery and the vehicle battery are quite different in that the power density, i.e., the number of watts that need to be stored in a unit weight and volume of a battery for a vehicle is well above that for electric utility application. The engineering work done to date shows that such a beta battery can be designed and that it will meet its requirements.

The General Electric-Chloride Silent Power effort is currently directed towards:

- Increasing the life of the cell. Currently cells can be charged and discharged daily for nearly 2 years whereas 5 years are required for commercial use.
- Deploying a small utility development battery within the next year or two to collect operation and maintenance data needed for the commercial design of such a battery.
- Having a larger scale utility beta battery ready for demonstration by the middle of this decade.
- Having a beta battery for fleet and van size electric vehicle demonstration also ready by the middle of this decade.

General Electric has investigated a wide variety of advanced battery technologies and it is our considered opinion that the beta battery is the best choice for further development from the standpoint of its ultimate potential and the remaining technical barriers to be overcome in development.

12/4/81

COMMENTARY ON
ELECTRIC VEHICLE BATTERY DEVELOPMENT
BY
GOULD INC.
ROLLING MEADOWS, ILLINOIS

GOULD

Gould is one of the worlds major suppliers of automotive, transport and industrial batteries, and is a leading developer of advanced battery technology. More than a decade ago, the company began to explore potential products for the emerging electric vehicle (EV) market. During the 1970's Gould embarked on two different paths involving EV development. In conjunction with AM General we produced the entire energy and propulsion system for over three hundred electric post office vehicles. However, it was recognized that the conventional lead-acid battery would not offer the driving range and acceleration desired for use in a large scale EV market. Gould, therefore, selected both the nickel/zinc and lithium/metal sulfide systems as candidates for a greatly improved EV battery.

In the mid-1970's the company began simultaneous major R&D programs for both of these battery types. In 1977 the DOE began to jointly fund those efforts with Gould. At that time, it appeared that the nickel/zinc battery would have market viability more rapidly than the lithium/metal sulfide battery, and Gould was willing to accept more than 50% of the R&D costs in its joint program with the DOE. In the case of the longer term lithium battery, Gould's cost participation has been about 30%. Gould's shared percentages have the largest of any contractor in both DOE's near-term and advanced EV battery programs.

The commercial EV market has not materialized in the originally expected time frame. Indeed, estimates of a substantial market in the early 1980's have given way to more tentative predictions for a possible market in 1987-88. As the time to commercialization increases, the potential payback time for expended R&D funds and invested capital for commercialization increase. The anticipated return on investment is decreasing and the company's view toward expending more and more funds on a less obvious market has become increasingly cautious.

It is at todays point in market development that government should take a hard look at its policies toward funding programs whose successful outcome could greatly benefit the national interest. In the case of EV, the benefits of significant EV utilization include: reduced oil imports, electric utility load levelling, reduced auto emissions, improved ability of the nation to withstand transient oil shortages, reduced urban noise, and potentially reduced life cycle costs for EV owners. In order to promote these public sector benefits, advanced technology development is properly supported by Federal financial participation.

Gould believes that the successful development and commercialization of advanced technology can, and should, result in compensating the government for its participation by sharing in future profits. The DOE has set a precedent for such a concept in its contract with the photovoltaic cell manufacturer, Solarex, of Rockville, Maryland. The DOE is funding the development of exploratory technology which could lead to a substantial reduction in the cost of producing photovoltaic arrays. In the event of a successful effort, Solarex will reimburse the government for the outlayed funds. Unfortunately, no similarly innovative arrangements have emerged from the DOE's EV program.

Because the market for large-scale EV introduction is essentially dependent on the participation of the major auto companies, and remains a moving target, Gould recently advised the DOE that we would have to eliminate our cost-share on the nickel/zinc program, with the suggestion that an innovative industry payback provision could be structured to continue the program. The DOE rejected Gould's suggestion and the nickel/zinc program was terminated. Our advanced lithium/metal sulfide effort is still on target, however.

Gould has worked extensively with the DOE, and with American and foreign vehicle manufacturers, in the development of appropriate batteries for EV. However, it appears at times that the automakers and the DOE are working at

GOULD

cross purposes. The automakers continue to require range and acceleration not available in state-of-the-art (or even advanced) lead-acid batteries. The automakers have repeatedly informed Gould that a successful EV must include an advanced high performance battery. Yet, the DOE continues to spend a large portion of its battery R&D funds on low performance lead-acid batteries. In its demonstration program there are currently no advanced batteries in vehicles, and there are plans for testing only a very small number of nickel/iron and zinc/chlorine batteries in that program.

Our position in the EV area is clear. Industry and government can cooperate to achieve the desired introduction of electric vehicles. The government should be a patron of the national interest and can be more active in supplying up-front, reimbursable development funds to major component suppliers. The petroleum savings and environmental benefits available from the large-scale introduction of EV can begin realization by the late '80's. Lastly, it is our observation that the DOE should more fully consider the requirements of the potential large-scale manufacturers of EV (the auto industry) when determining where funds can most productively be spent to achieve the desired goals of the EV program.

Gould Incorporated
Rolling Meadows, Illinois
March 1980

Elton J. Cairns
Lead Center Project Manager
Lawrence Berkeley Laboratory
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BATTERY AND ELECTROCHEMICAL RESEARCH: THE NEED FOR A STRONG FEDERAL PROGRAM

Elton J. Cairns and Frank R. McLarnon

EXECUTIVE SUMMARY

A renaissance in battery research has been underway for about 10 years. This has been due, in part, to a worldwide technical "race" to develop suitable batteries for utility load-leveling purposes and electric vehicle applications. The U.S. has a competitive position at present, with leadership in several of the candidate technologies. The potential benefits of successful technology development are great and include (a) the emergence of a major new industry, and (b) potential crude oil savings of up to 435 million barrels of oil equivalent (MBOE) per annum by the year 2000.

A vigorous federally funded battery R & D program is *essential* if the U.S. is to reap these enormous benefits. This is necessary because the battery developers and the utilities do not have sufficient funds available for long-term high-risk R & D projects of the size and scope required to develop new technologies. Narrow profit margins require the battery industry to spend 90 percent of its small R & D budget to improve present products in order to remain competitive in existing markets. Industrial sponsorship of long-term, high-risk battery R & D is very small because there are no existing markets for consumer electric vehicles and utility load-leveling devices. Government participation allows industry to broaden its scope and engage in research which it would otherwise have to ignore or postpone.

It is strongly recommended that the U.S. maintain its competitive position in battery technology through continued federal support on two fronts: (a) fundamental generic research in electrochemistry and electrochemical engineering, and (b) development of the leading battery candidates.

WHY DO BATTERY RESEARCH?

A Historical Perspective

Man's search for practical devices which store and concentrate energy extends back thousands of years. As chemistry and electricity began to be understood in the 18th and 19th centuries, inventors learned that energy could be stored in a device which combined useful features of both -- namely the electrochemical cell. The first practical uses for these new storage cells involved railroad, telephone, and illumination applications. Around 1900, vehicle applications became more important -- first in automobiles totally powered by batteries, and later for starting power for internal combustion vehicles. Today, batteries are an integral part of society with hundreds of practical uses ranging from flashlights to satellite power sources.

The Need for Energy Storage

The electrical portion of the U.S. energy economy has been growing at

a faster rate than any other portion. It now represents 30% of all the energy consumed in the U.S., and is expected to be 36% by the year 2000. Nuclear energy is the fastest-growing source of electrical energy, and wind- and solar-electric systems are among the next generation of systems to be available. One feature that all of these systems have in common is the strong benefit (in some instances, the *necessity*) of the use of energy storage as part of the system. Energy storage devices such as advanced batteries make possible the matching of the load with the energy supply (load-leveling), providing energy storage for periods of several hours to several days. Without energy storage, load following is either impractical (for nuclear) or impossible (for stand-alone wind and solar). Peaking power, which is presently provided by relatively inefficient, petroleum-consuming gas turbines, could be provided by advanced batteries. Because of the fact that there is no opportunity to decrease the use of petroleum in peaking turbines, and because energy storage couples in an important way with the needs of nuclear power plants, there is a strong national incentive to support battery energy storage R & D for these ultimate applications.

Energy storage in advanced batteries makes possible electric automobiles and vans that can serve the important purpose of shifting a portion of the transportation energy demand away from petroleum, and toward coal, nuclear, and other domestic energy sources. This opportunity is extremely attractive from a national energy security point of view, but represents a long-range high-risk research area.

The Renaissance in Battery Research

The very real possibility of immense electric-vehicle and utility load-leveling markets has created a technological race to develop a suitable battery. A number of laboratories in Western Europe, Japan, and the U.S. have entered this competition, the result of which is a worldwide renaissance in battery technology. About 10 advanced battery systems are being developed for this application, and impressive technical advances have been made. Even lead-acid battery technology which was dormant for 50 years has made recent progress -- about 50 percent improvement in specific energy (storage capacity per unit weight) and 100 percent in cycle life. The timeliness of these advances is underscored by recent announcements by General Motors and Ford that they intend to market electric vehicles as soon as battery technology permits. However, the technical barriers facing battery developers are numerous and difficult, and an intensive multi-year program of battery research is required before a battery of suitable performance, durability, and cost will be available.

Potential Benefits Are Massive

The potential rewards of successful advanced battery development are enormous. Transportation experts project that a suitable advanced battery would ultimately result in about a 50 percent penetration of the vehicle market, and there would be comparable impact on the utility load-leveling market. The resulting new industry to produce electric vehicle and load-leveling batteries could eventually achieve annual sales measured in tens of billions of dollars. Advances in our nation's battery technologies would enable U.S. industry to be competitive in these new markets. Poten-

tial savings by the year 2000 amount to 435 MBOE per year, which represents a major step toward energy independence and a reduction of federal deficits caused by purchases of foreign petroleum.

THE COMPETITIVE ENVIRONMENT

U.S. Technical Position

Leadership in battery technology presently resides in the U.S., Japan, and Western Europe. The central focus of this nation's R & D has been the Energy Department's programs to develop advanced batteries for electric vehicles and electric utility systems. As a result of these programs, the U.S. has an apparent technical lead in several of the candidate batteries and a competitive position in the others. However, the U.S. does not enjoy a clear-cut superiority in electrochemistry, and in recent years we have been an importer of electrochemical technology. Continued federal support would allow the U.S. to maintain its momentum to establish a firm competitive edge in electrochemical technology.

Industry Needs Help

It is clear that industry alone will not pursue battery R & D at the required level of effort. Some of the reasons are:

- There is a cost barrier to the industrial development of advanced batteries suitable for electric vehicle use. Only 1.7 percent of the revenue from sales made by battery developers is returned to their R & D program. Of that, 90 percent is used to improve products for existing markets, and support for R & D work directed at long-term potential is at most 0.17 percent of sales. The reason for lack of industrial spending on this R & D is that there is no well-developed market for electric vehicles; therefore the cost and risk are both high.
- Narrow profit margins throughout the highly competitive battery industry make technology shifts risky. For example, to make current technology batteries profitable to utilities, the designs must be improved to double the system life (from the current 10 to about 20 years), and the costs must be reduced by about 50 percent. This would require large investments over a relatively long period of time (5 to 15 years), requiring resources the battery companies do not have.
- There is a technical risk which adds additional weight to the economic risk. This risk involved the development of batteries that require substantial and simultaneous improvement in four competing areas of performance: specific energy, specific power, cycle life, and cost. For example, without extensive battery development, electric vehicles will continue to suffer from an unfavorable position relative to ICE vehicles in terms of cost and performance.

Long-range R & D on advanced batteries for energy storage is a highly appropriate use of public funds because of the broad range of positive impacts that could accrue to various national programs (nuclear, fossil, and renewable energy) and national problems (dependence on foreign petroleum, federal deficits, and damage to the environment). The absence of existing markets for the eventual application of advanced batteries makes long-range R & D a high-risk undertaking, which underscores the crucial need for continued government support.

BATTERY R & D TODAY

The Battery Candidates

There are several battery systems which are attractive candidates for electric vehicle and load-leveling applications. Each has particular advantages as well as formidable technical barriers.

Lithium/Metal Sulfide

This high-temperature battery system was invented by a national laboratory in the early 1970s, and is a candidate for both stationary and mobile applications. The key R & D barriers include cycle life, development of a low-cost separator, and development of a higher-performance positive electrode. The U.S. has clear worldwide leadership in this battery technology.

Sodium/Sulfur

Invented in the 1960s, this high temperature battery system offers the potential of exceptional performance using abundant, low-cost active materials. Cycle life of the solid ceramic electrolyte needs improvement to meet the demands of the intended stationary and mobile applications. Several years of research, especially in the area of material science, are needed for this system.

Alkaline Batteries

The most promising alkaline system is the zinc/nickel oxide battery. Its power capability and energy capacity are both outstanding, but present cycle life is inadequate. Fundamental research is required to achieve improved understanding of the life-limiting mechanisms -- this knowledge could lead to methods for improving the life of this system without compromising other attractive features. This battery is targeted for mobile applications, but must be considered in the exploratory stage.

Zinc/Halogen

The zinc/chlorine and zinc/bromine systems are viable candidates for load-leveling applications. System complexity and halogen safety are key R & D issues.

Metal/Air

Either aluminum, iron, or zinc can be used with an opposing electrode which consumes oxygen from the air. This feature is attractive because the air electrode eliminates the necessity of carrying part of the "fuel" in a mobile battery. The engineering and electrochemistry of a practical air electrode, either primary or rechargeable, is a key long-term project.

Impact of Federal Support

The U.S. Department of Energy has been carrying out, as part of its

energy storage program, electrochemical R & D work in support of advanced batteries. Specific accomplishments include:

- The original and continuing work on high-performance molten-salt batteries for potential use in electric vehicles and stationary energy storage (lithium/metal sulfide cells).
- Key support for a new family of high-temperature batteries using solid electrolytes, suitable especially for stationary energy storage (sodium/sulfur).
- The discovery and evaluation of new materials for advanced battery application, including alkali ion-conducting ceramics, glasses and polymers; novel molten salts; and electronically conductive polymers for possible use as battery electrodes.
- A large portion of the R & D work on high-performance ambient-temperature lithium cells (for electric vehicle applications).
- Major advances in ambient-temperature alkaline cells for electric vehicle applications. Improved performance and life.
- Major advances in flow batteries, especially attractive for stationary energy storage (Redox systems and zinc/halogen).
- Metal/air systems for electric vehicle applications, where high specific energy is important (aluminum/air and iron/air).

Winners Will Emerge

It is important to keep in mind the history of secondary battery development. During the 1800s only a single practical battery system emerged -- namely lead-acid. By the early 1900s, iron/nickel oxide batteries became available, in the 1960s cadmium/nickel oxide and zinc/silver oxide batteries were developed, and in the 1970s, hydrogen/nickel oxide batteries were employed in space applications. These systems have seen increasing application in both aerospace and consumer markets. It is clear that new systems require long periods of R & D to come to the market place, but with proper incentives and with federal involvement winners will continue to emerge. Thus, while the probability of success in any one of the above battery systems may be 50 percent or less, continued research is virtually certain to result in the successful development of a number of these.

RECOMMENDATIONS

It is recommended that the Energy Department's electrochemical energy storage program continue to receive the support* that has made possible the existing strong R & D effort, which has involved major research institutions, including:

- National Laboratories

  Lawrence Berkeley Laboratory
  Sandia National Laboratory
  Lawrence Livermore National Laboratory

*Total FY 1981 DOE funding was $26.25M.

- National Laboratories, continued

  Argonne National Laboratory
  Los Alamos National Laboratory
  Brookhaven National Laboratory

- Universities

  University of California
  Case Western Reserve University
  University of Pennsylvania
  Massachussetts Institute of Technology
  Stanford University
  University of Tennessee

- Industrial Laboratories

  Gould, Incorporated
  Johnson Controls Incorporated, Globe Division
  Exide Technology Company
  General Motors Research Laboratories
  Westinghouse Electric Corporation
  Eagle-Picher Industries
  Ford Aerospace and Communications Corporation
  C & D Batteries
  Exxon Research and Engineering Company
  Energy Development Associates
  Diamond Shamrock Corporation

Specifically, continued Federal support should include the following elements:

- Research and development on the most promising battery candidates for both electric vehicle and utility applications should continue to the point of technological transfer to industry.

- Fundamental and applied research in electrochemistry and electrochemical engineering should receive greater emphasis. This research provides the scientific framework necessary for advancement of battery technology, development of new electrochemical couples, and the identification of promising new materials.

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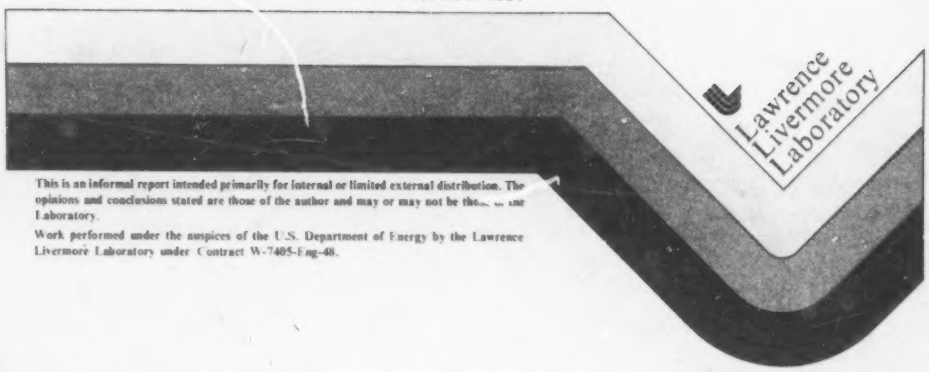
THE RAPIDLY-REFUELABLE 167-CM^2 ALUMINUM-AIR POWER CELL

Robert V. Homsy

November 1981



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SYMBOLS

a_{eq}	equivalent cell width, 6.12 in
b	interelectrode separation, 0.125 in
G	volumetric flow rate, litre/min
h	vertical distance between electrolyte pressure taps, in
i	current density, kA/m^2
I	current, A
ΔP	pressure difference, psi
R	electrical resistance, ohm
Re	Reynolds Number

Greek

η	deviation of electrode potential from average of 25- and 1000-cm^2 cell results
κ	electrical conductivity of electrolyte, 0.546 S/cm
ν	kinematic viscosity of electrolyte, 0.0107 cm^2/s
ρ	density of electrolyte, 1.163 g/cm^3
ϕ_{ohm}	ohmic potential drop, ohm

Subscripts

air	air
A	anode
C	cathode
el	electrolyte
h	hydrostatic
in	in
out	out

SYMBOLS (cont.)

R	reference electrode
1	cell 1
2	cell 2

THE RAPIDLY-REFUELABLE 167-CM^2 ALUMINUM-AIR POWER CELL

ABSTRACT

The rapidly-refuelable, 167-cm^2 aluminum-air power cell has been successfully tested both as a single cell and as a two-cell stack. This cell, which features a moving cathode and internal manifolding of electrolyte, is designed for rapid replacement of the anode and easy construction. A maximum power density of 4.2 kW/m^2 was measured, which is 97% of that obtained earlier in the 25-cm^2 cell. Cathode polarization was negligibly affected by air flow rate and air-electrolyte differential pressure across the air cathode.

INTRODUCTION

The aluminum-air battery is being developed at Lawrence Livermore National Laboratory (LLNL) for general-purpose, electric-vehicle propulsion.[1] The power cell reacts aluminum, sodium hydroxide, tap water, and atmospheric oxygen to produce electricity and sodium aluminate (hereafter referred to as aluminate). Cells ranging 25 to 1000 cm^2 in size and of many designs have been built and tested over the past three years.

During FY 1981, various rapidly-refuelable cells were developed, that are suitable for assembling into a cell stack. This work was performed both by LLNL and Lockheed Missiles and Space Company (LMSC), under subcontract. The LLNL design features a moving cathode, that advances as the aluminum anode dissolves. The LMSC cells feature not only this type of design, but also the moving anode. The LLNL cell was developed and

tested on a subscale (167 cm^2), and designed for easy construction and rapid disassembly. This report documents tests of both a single cell and a two-cell stack, designated M1-1 and M2-1, respectively. These results are intended to be eventually combined with work continuing in the first quarter of FY 1982, in which the number of cells in the stack will be further increased up to a maximum of six, or until a technical limit is reached.

SINGLE CELL, M1-1

Three tests of M1-1 were performed at LLNL; the first two were conducted by Cooper and are reported elsewhere.[2] These tests resulted in certain cell-design and test-stand modifications, that were incorporated in the final test, designated M1-1-3.

Apparatus

Cell Design

Figure 1 shows a schematic of the cell with anode assembly on the left and cathode on the right. The anode is attached to a sheet of copper-clad, fiber-filled epoxy (electronic-circuit board material) by soldering 16 silver leaf strips (0.002 x 0.5 x 2.5 in) to its back. This sheet acts to support the anode and to collect current. The copper surface exposed to electrolyte is coated with glue (Silastic, 140 RTV, Dow Corning Corporation, referred to hereafter as RTV), and the edges of the anode are coated with epoxy (EA 9410, Dexter Corporation). A fillet of RTV is then placed between these edges and the supporting sheet. Current is collected by a copper bus bar (0.040 x 0.5 x 11 in), soldered to the supporting sheet. An interelectrode separator is used, that has six, vertical triangular ribs of the same design as in the 1000-cm^2 cell.[3] The cathode and separator advance together continuously as the anode dissolves, so as to maintain a

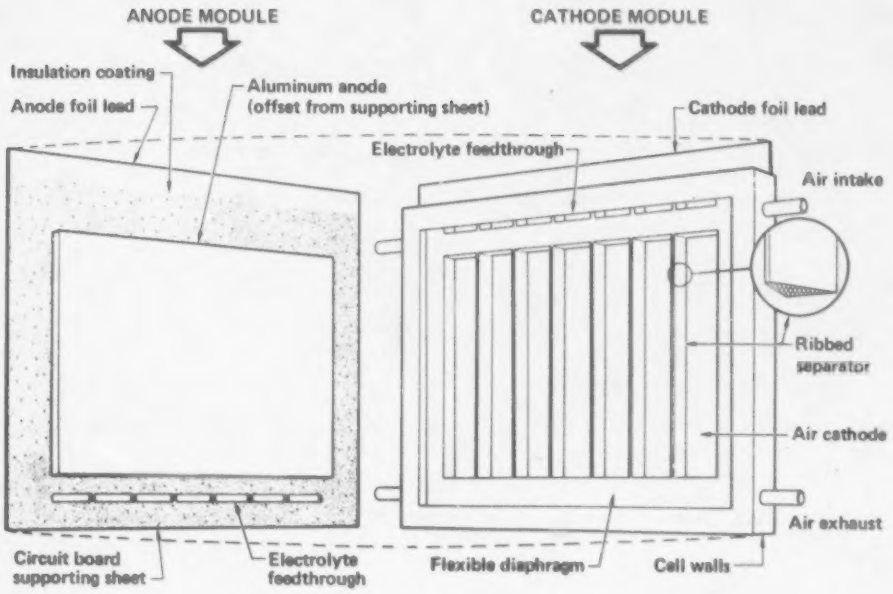

FIG. 1 Schematic of the rapidly-refuelable, 167-cm^2 aluminum-air power cell.

constant interelectrode gap of 0.32 cm (0.125 in), denoted by b. Air flows into the chamber on the back side of the cathode at the top and on both sides of the cell. The chamber is filled with reticulated polyurethane, a porous, compressible material used to promote dispersion of the air. The cathode assembly is advanced automatically by the pressure of both the polyurethane and the air, which is always maintained in excess of the electrolyte. A seal between air and electrolyte is established by a flexible polyvinylchloride (PVC) diaphram (0.018 in), that is cemented to the separator and cell wall by epoxy (0151 Epoxy, Dexter Corporation). Air is exhausted through two ports at the bottom and on either side of the cell. Any electrolyte that weeps through the cathode is thereby easily swept out of the air chamber. Current passes through the cathode grid (nickel-plated copper screen) and to a sheet of circuit-board material via 16 silver leaf strips (same as for anode), that are soldered around its perimeter. A bus bar to remove current is soldered to the top of the current collector, as was done for the anode.

The M1-1 cell features internal electrolyte manifolding. Electrolyte enters through an end plate in front of the anode and flows up within the interelectrode chamber through seven feedthrough ports (0.25 x 0.75 in) at the bottom of its supporting sheet. Exit is through similar ports at the top, that are cut through the cathode supporting sheet. The electrolyte then flows down the backside of the cathode, where it either continues on into the next cell, if there is a stack of more than one cell, or it exits through an end plate. The backside down-flow provides a high resistance to internal shunt current. Two compressible PVC baffles are mounted on either side of the interelectrode separator frame to discourage channeling of the electrolyte through the gaps on either side of the anode. These channels are gradually closed, as the anode dissolves and the cathode advances. The baffles are made compressible, so as to allow this movement.

The cell is sealed by O-rings on both end plates and is bolted together by 20 screws. Electrical potential of the electrodes is measured by probes that are soldered directly to their surfaces, so as to avoid any ohmic losses through the current collectors. Pressure taps are mounted at three positions in the cell: midway up the cell in the air chamber, and within the electrolyte cavity at both the inlet and outlet feedthrough ports.

Test Stand

Figure 2 is a schematic of the test stand used in the M1-1-3 experiment. It is essentially the same as was used for the 1000-cm^2 cell tests.[3] Air is first dried in a column of drierite, scrubbed of carbon dioxide in a soda-lime column, and then passed through a flowmeter, whose discharge curve is shown in Fig. 3. As recommended by the cathode manufacturer,[4] air is neither humidified nor preheated prior to reacting in the cell. Air exits from the cell into a trap, where the electrolyte that has weeped through the cell is collected. The air back pressure on the cathode is controlled by submerging the exiting air tube into a column of water. The column is equipped with a vent and may be drained or filled with distilled water, so that its level may be controlled easily.

Electrolyte is stored in the 8-litre tank that was used previously in the MO-1-7 (simultaneous discharge and crystallization) experiment.[3] This tank is equipped with two 465-W electric immersion heaters, a cooling water heat-exchanger, thermometer, thermocouple (in a casing filled with mineral oil), and a mercury/mercuric oxide (Hg/HgO) standard reference electrode. The top of the tank is covered with a flexible sheet of PVC, fitted with a hole that allows hydrogen gas to be vented. Gas exiting from this vent is captured in an overhead hood, equipped with a suction blower. Electrolyte is pumped from the tank through a flow meter, into the cell, and back into the tank. Temperature of the electrolyte exiting the cell is measured by thermocouple. Flow rate is also measured by timed collection of a known electrolye volume, for more accuracy.

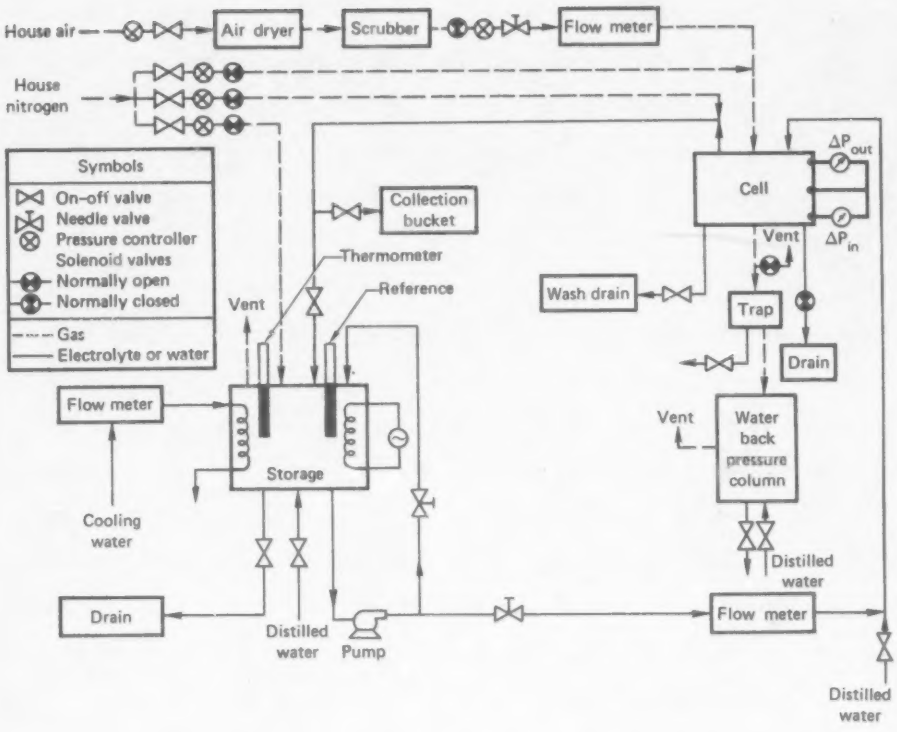

FIG. 2. Test stand schematic for the single-cell experiment, M1-1-3.

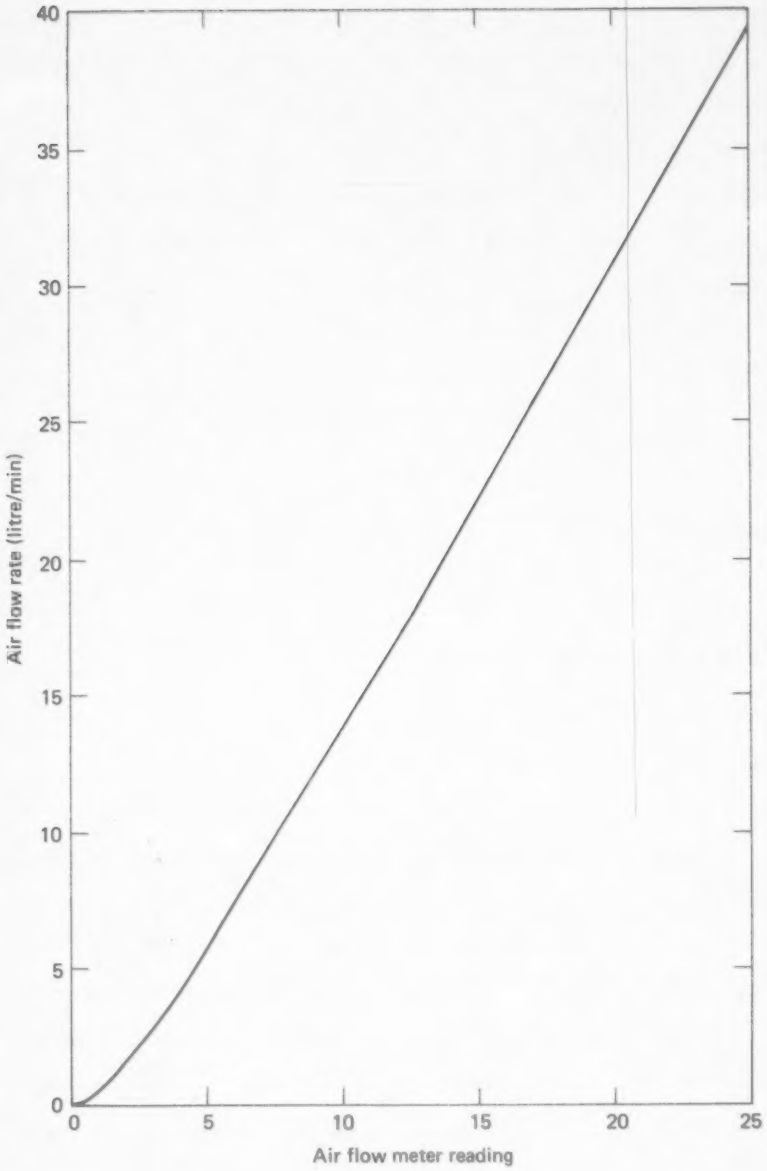

FIG. 3. Calibration curve for air flow meter.

Flow of electrolyte returning to the tank may be diverted to a collection bucket for this purpose. The electrolyte tank is also equipped with a drain and distilled water lines to facilitate shutdown and washing.

Two pressure transducers (± 5 psi) are fitted to the pressure ports on the cell to measure differential pressure between the air and the entering and exiting electrolyte, ΔP_{in} and ΔP_{out}, respectively. Here

$$\Delta P_{in} = P_{air} - P_{el_{in}} , \tag{1}$$

and

$$\Delta P_{out} = P_{air} - P_{el_{out}} . \tag{2}$$

These measurements, as well as their average, the pressure difference between air and electrolyte at the midpoint of the cell,

$$\Delta P_C = \frac{\Delta P_{in} + \Delta P_{out}}{2} = P_{air} - \frac{P_{el_{in}} + P_{el_{out}}}{2} , \tag{3}$$

are displayed digitally on the control chassis.

The system is equipped with six electrically-operated solenoid valves, that are used for normal shutdown purposes, as well as for emergency. The solenoid valves are chosen such that in their normal, de-activated position, the cell is automatically drained of electrolyte and purged on both air and electrolyte sides with nitrogen. The electrolyte storage tank is also purged with nitrogen. These valves and the electrolyte pump are controlled by a single power switch. Distilled water is plumbed into the electrolyte stream for washing the cell following shutdown. Wash water is collected in a 5 gal-drain tank.

Current is controlled by varying the external resistance of two, 3-kW carbon-pile resistors.[3]

Data Collection and Storage

The following eight operating variables are collected and stored during experimental testing of the M1-1 cell: time, current, cell potential, cathode and anode potentials (relative to the Hg/HgO reference electrode), inlet, outlet, and midpoint differential pressures between air and electrolyte. These variables are scanned on command and stored on magnetic disk. Details of this system may be found elsewhere.[3]

Procedure

The standard electrolyte used in all tests reported here is a solution of 4M sodium hydroxide, 1M aluminate, and 0.06 M sodium stannate at 60° C. An electrolyte volume of 4 litre was used in the M1-1 cell test. This value was chosen such that for a 3-h experiment with an average discharge anodic-current density of 1.8 kA/m^2, and coulombic efficiency of 0.83 (denoted as SC for standard condition), the aluminate concentration of the electrolyte will increase 35%.

The cell is charged with a 0.25-in aluminum anode (Reynolds Aluminum, 0.07% gallium alloy) and an air cathode (Diamond Shamrock Corporation (DSC) No. 36AB269-50E562T-21), containing 1.2-mg Pt/cm^2 catalyst loading. Active surface area of each electrode is measured, and the cell assembled and mounted on its stand. Electrolyte is preheated by circulation through the cell by-pass line. Once steady state is established, electrolyte is slowly introduced into the cell up to a rate of 0.079 litre/s, while air is simultaneously increased to 16.1 litre/min. This electrolyte flow rate

corresponds to a Reynolds Number of 936, as calculated by

$$Re = \frac{2\,G_{el}}{(a_{eq} + b)\nu} \quad , \tag{4}$$

where a_{eq} = 6.12 in, is the equivalent cell width, and ν = 0.0107 cm^2, is the kinematic viscosity.[5] This air flow rate provides 10 times the stoichiometric oxygen consumption rate at an average current density of 5.2 kA/m^2, the maximum planned for this experiment. The air back pressure is also increased in order to maintain an average differential pressure ΔP_C of 0.16 psi. After a period of operating at open circuit to break in the air cathode, the load is increased slowly up to a maximum current of 90 A, while cell performance data is periodically collected. Following the various tests of the cell and prior to shutdown, electrolyte flow rate is measured by timed collection of 0.5 litre of solution. The cell is then drained and purged with nitrogen, and finally rinsed thoroughly with distilled water. The cell is dissassembled and the electrodes inspected. Two samples of the electrolyte are taken before and after an experiment and are analyzed for aluminate concentration by measuring its electrical conductivity.[6]

Results and Discussion

The M1-1-3 experiment successfully ran for slightly more than 1.5 h. In addition to measuring polarization over the range of average current density of 0 - 5.2 kA/m^2, cathode performance at SC was observed over a range of air flow rate corresponding to 2-24 times stoichiometric, and an average differential pressure of 0.4 - 0.8 psi.

The cell was broken in slowly with 15 min operating at open circuit. Cell current was initially increased at a rate of 1A/min to 12A, followed by 2.5A/min to 45 A, and

finally 10A/min up to the maximum current of 90A. This maximum was chosen so as to yield a maximum current density of 5.2 kA/m^2, based on an average active electrode area of 173.2 cm^2. Anode and cathode active surface areas were measured to be 167.7 and 178.7 cm^2, respectively.

During start up, it was found that with no back pressure applied to the air cathode, and at an air flow rate of 7.2 litre/min, the average differential pressure was 0.5 psi. This condition prevented obtaining the desired operating conditions of 16.1 litre/min air flow rate at an average differential pressure of 0.16 psi. It was concluded that this was due to the prohibitively large pressure drop in the two ports through which air exits the cell. Nevertheless, polarization tests were run at this lower air flow condition, since adequate supply of oxygen is still provided at 2.2 times stoichiometric at maximum current. Electrolyte flow rate was measured to be 0.093 litre/s, which corresponds to a Reynolds Number of 1100. The flow meter read 1.5 gpm, calibrated for water at 25° C.

Four tests were performed on the M1-1 cell, and are designated M1-1-3-n, where n is the test number. Tests 1, 3, and 4 are polarization scans, while the second investigates the dependence of cathode polarization upon air flow rate and air-electrolyte differential pressure. A complete listing of operating variables for all tests may be found in Appendix A.

Figure 4 shows polarization curves for cell and electrode potentials of the M1-1-3-3 test. Results of earlier 25- and 1000-cm^2 cell tests are included for comparison. M1-1 cell potential consistently lies between that obtained in these earlier tests, with the 25-cm^2 results[7] being best. Electrode potentials, however, are both shifted positive to previous results. An explanation for this behavior may be found by quantitatively

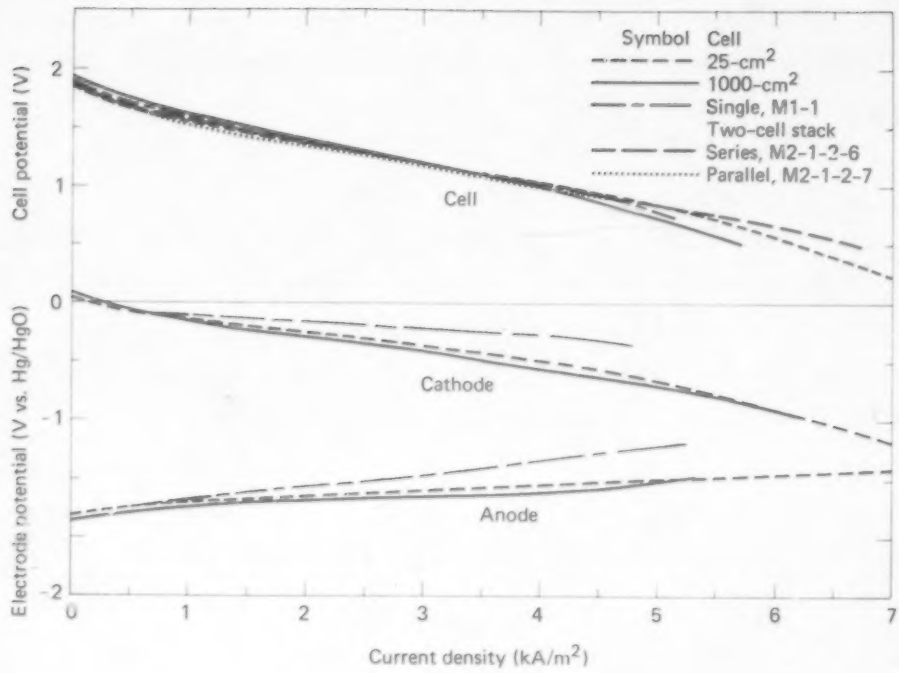

FIG. 4. Comparison of polarization of the rapidly-refuelable, 167-cm^2 cell with the 25- and 1000-cm^2 cells.

examining the magnitude of these deviations. Table 1 shows the deviation of cathode and anode potentials, V_{C-R} and V_{A-R}, from their values midway between 25- and 1000-cm^2 cell test results, denoted as η_C and η_A, respectively. Also shown is the ohmic potential drop across the interelectrode gap, as calculated by the expression,

$$\phi_{ohm} = \frac{ib}{\kappa} \quad , \tag{5}$$

where κ = 0.546 S/cm, is the electrical conductivity of the electrolyte.[6] Comparison of these values shows that the ohmic drop is essentially equal to the deviation in electrode potential. This implies that the reference electrode equivalent position (REEP) is <u>at</u> the surface of the cathode, and that the anode potential includes <u>all</u> of the ohmic drop. This conclusion contradicts an earlier assumption made in the 25- and 1000-cm^2 cell tests, where the REEP was taken to lie midway between the working electrodes, so that the ohmic drop is split equally between their potentials. This assumption was based on the fact

TABLE 1. Deviation in electrode potentials is equal to the ohmic drop.

i (kA/m^2)	ϕ_{ohm} (V)	V_{R-C} (V)	η_C (V)	V_{R-A} (V)	η_A (V)	V_{R-C}^* (V)
1	0.06	0.13	0.02	1.70	0.02	0.09
2	0.12	0.19	0.09	1.58	0.07	0.12
3	0.17	0.25	0.14	1.46	0.16	0.15
4	0.23	0.31	0.21	1.35	0.24	0.18
5	0.29	0.41	0.27	1.21	0.30	0.20

* Quality control test run No. 705 of DSC cathode No. 36AB269-50E562T-21.[8]

that electrodes in these cells are positioned exactly opposite one another and are identical in size. If the inferences drawn here are correct, then for these cells, the REEP in fact is at the surface of the anode, and all the ohmic drop is included in the cathode polarization. Results of cathode quality control tests performed at DSC are also shown in Table 1. These results were obtained with a capillary reference electrode located at the surface of the cathode, and are thus free of ohmic drop. Polarization is consistently less than observed in the M1-1-3 cell, which is in agreement with our observations.

Figure 5 shows power density of the M1-1 cell. Results of the 25- and 1000-cm^2 cells are included for comparison. Maximum power density of 4.2 kW/m^2 was obtained at 4.3 kA/m^2. This value is 97% of that obtained in the 25-cm^2 cell.[7]

Cell performance was found to have little dependence upon both the air flow rate and air-electrolyte differential pressure. As was already discussed, these parameters could not be varied independently, because of design restrictions in air outflow lines. Nevertheless, throughout the range of variation in these parameters of 1.1 - 13.6 litre/min in air flow rate, corresponding to 2.0 - 24.4 times stoichiometric, and of 0.38 - 0.80 in average differential pressure across the cathode, the cell potential varied a maximum of only 1.2%.

The difference between inlet and outlet air-electrolyte differential pressure is equal to the electrolyte pressure drop in passing through the cell,

$$\Delta P_{out} - \Delta P_{in} = P_{el_{in}} - P_{el_{out}} . \qquad (6)$$

The average difference for 31 data of M1-1-3-1 is 0.24 psi. This value may be

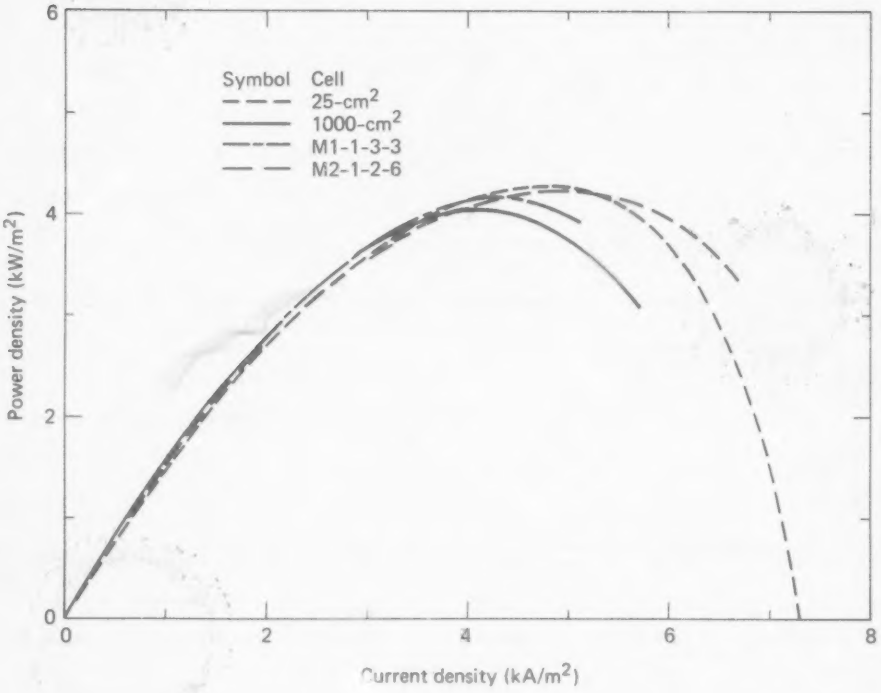

FIG. 5. Comparison of the power density of the rapidly-refuelable, 167-cm^2 cell with the 25- and 1000-cm^2 cells.

compared with an electrolyte hydrostatic pressure head of 0.23 psi, calculated by

$$\Delta P_h = \rho h \ , \qquad (7)$$

where $\rho = 1.163$ g/cm^3, is the electrolyte density,[5] and h = 5.5 in, is the vertical distance between electrolyte pressure taps. Thus, we may conclude that the viscous pressure loss in the electrolyte caused by flowing between the electrodes in the cell is negligible (0.01 psi).

Table 2 shows the aluminate concentration of the electrolyte before the M1-1-3 test. Unfortunately, the sample taken after the experiment was contaminated and thus gave erroneous results.

TABLE 2. Sodium aluminate concentration of electrolyte before and after testing the rapidly-refuelable single cell and double-cell stack, M1-1-3 and M2-1-2, respectively (mole/litre).

Test	M1-1-3	M2-1-2
Before	1.00	0.94
After	--	1.24

TWO-CELL STACK, M2-1

Two tests of the rapidly-refuelable, two-cell stack were performed at LLNL. The first, designated M2-1-1, was aborted due to an internal leak in the cell. The second test, M2-1-2, was successful. Certain modifications in cell design and test-stand configuration were necessary to operate two cells simultaneously.

Apparatus

Cell Design

Only slight modifications were made in the cell design for the two-cell stack. The size and shape of the electrolyte feed through ports within the cell were changed to make fabrication easier. Electrolyte enters at the bottom of the cell through six, horizontal ports (0.25 x 0.875 in), and exits at the top through a set of 25 circular holes, 0.25-in diameter. Air inlet and outlet ports were expanded to 0.375-in diameter in order to decrease the prohibitively-large pressure drop encountered in M1-1-3. Pressure taps for the entering electrolyte are mounted below the cell, so that the vertical distance between inlet and outlet taps is increased to 10.5 in.

Test Stand

Figure 6 is a schematic of the test stand used in the M2-1-2 experiment. Modifications in the stand were necessary in order to operate two cells simultaneously. Air is manifolded after exiting the flow meter and prior to entering the cells. Each stream then passes through a trap and into the backpressure water column. Each cell is equipped with two solenoid valves, one to drain electrolyte from its chamber upon shutdown, and the other to vent the air side of the cell.

Two pressure transducers in the system are used to monitor differential pressures in each cell. Three-way valves are connected between the electrolyte inlet and outlet and the air in each cell, with the latter being common. This configuration permits air-electrolyte differential pressure measurement of the inlet and outlet streams by switching the three-way valves.

Provision is made in the system for series, as well as parallel electrical connection.

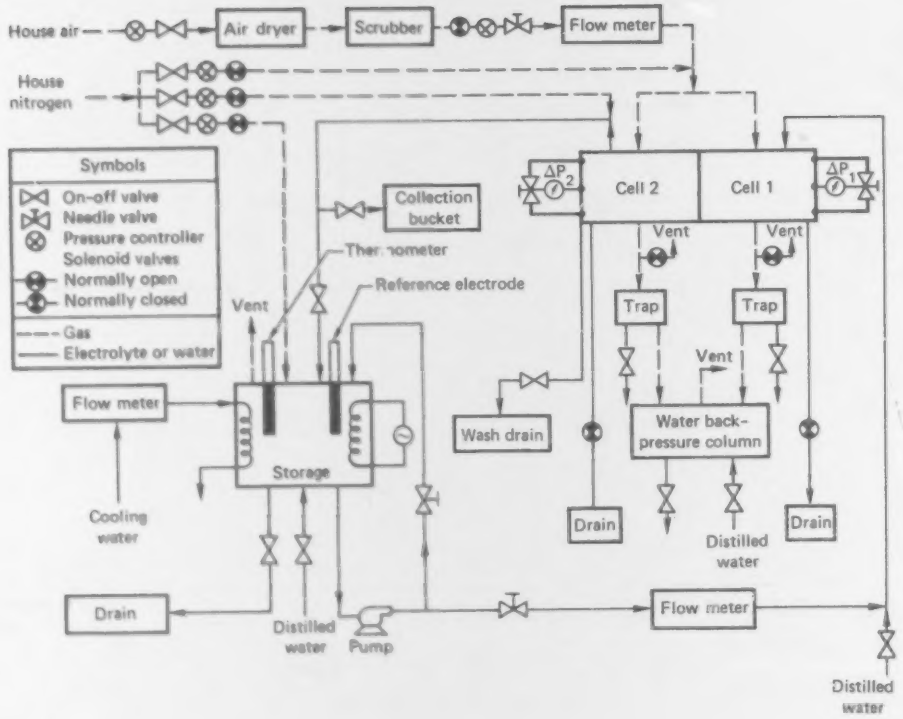

FIG. 6. Test Stand Schematic for the two-cell stack experiment, M2-1-2.

Data Collection and Storage

Four additional operating variables are collected and stored for the testing of the M2-1 cell, and one is excluded. This constitutes a total of 11 channels. Those added are: the potential of cell 2, its cathode and anode potentials (relative to the Hg/HgO reference electrode), and the overall potential of the cell stack. The average of the two differential pressures is eliminated.

Procedure

The cells are charged with two air cathodes (DSC No. 35AB276-50E578T-36), assembled, and tested following the same procedure as for the M1-1 cell. Electrolyte volume is doubled to 8 litre.

Results and Discussion

The M2-1-2 experiment successfully ran for about 2.75 h. Polarization was measured over an extended range of current density of 0-6.7 kA/m^2, and cathode performance at SC was observed over a range of air flow rate corresponding to 2-12 times stoichiometric and average differential pressure of 0-0.7 psi.

The cells were broken in slowly as before, with 16 min operating at open circuit. Current was increased steadily at a rate of 1.5A/min to a maximum of 90A. Active area of each electrode was the same as before. Air was set at 12.8 litre/min, a value that provides 4 times stoichiometric at maximum current. Differential pressure between air and exiting electrolyte of cell 1 was set at about 0.3 psi, a value sufficiently large (greater than 0.23 psi, as determined from M1-1-3), to assure air pressure in excess of electrolyte at the bottom of the air cathode. Corresponding differential pressure of cell 2,

however, was 0.18 psi larger than this value, indicating that the electrolyte pressure dropped by this amount in flowing through one complete cell. Efforts to equalize these pressures by decreasing the air back pressure in cell 2 failed, because by so doing, the air flow rate to cell 1 was significantly decreased. This problem can be avoided in the future by providing separate air supply to each cell in the stack.

Electrolyte flow rate was measured to be 0.057 litre/min, which corresponds to a Reynolds Number of 666. The flow meter was set at 1.25 gpm.

Seven tests were performed on the M2-1 cell. Tests 3 and 4 investigate the dependence of cathode polarization upon air-electrolyte differential pressure and air flow rate, respectively, while the others are polarization scans. The last test is with parallel electrical connection of the cells, while the others are with series connection. See Appendix B for a complete listing of the operating variables.

Figure 4 shows the average cell potential for the M2-1-2-6 test. Below 5.2 kA/m^2 the cell potential lies between that measured for the M1-1 and 25-cm^2 cells, while above this value, it surpasses all other results. Electrode potentials are not shown in the figure, since the location of REEP is ambiguous in a cell stack, and the meaning of observed values is questionable. This problem may be circumvented by using separate Luggin capillaries positioned at the surface of the electrodes.

During testing of M2-1-2, cell 1 consistently outperformed cell 2; at 2.9 kA/m^2, the difference in cell potential is 2.3%. This behavior may be explained by observing that the differential internal resistance of the two cells, defined by

$$R_{1,2} = \frac{V_{C\text{-}A_1} - V_{C\text{-}A_2}}{I} , \qquad (8)$$

is 0.7 mohm. This difference may be caused by excessive cathode polarization in cell 2, or increased resistance between electrodes. When the electrodes were inspected, following shutdown of the experiment, it was found that portions of the anode active surface were accidentally coated with RTV and thereby insulated. This may have caused the observed increase in internal resistance.

For series electrical connection, the sum of the potentials of cells 1 and 2 exceeds the measured potential of the cell stack. This difference is due to the ohmic potential drop associated with current collection on the cathode of cell 1 and on the anode of cell 2, and the electrical connection between the two. This combined resistance is 2.25 mohm.

Power density is nearly the same as obtained in M1-1 and extends over a larger range of current density. Maximum power density of 4.2 kW/m^2 was obtained at 4.6 kA/m^2.

For parallel electrical connection, cell potential is about 2% lower than the average value for series connection. Figure 4 shows the results for M2-1-2-7. Maximum current density for this configuration was 4.67 kA/m^2, while a maximum power density of 4.1 kW/m^2 was observed at 4.5 kA/m^2. This value is 95% of that obtained in the 25-cm^2 cell.[7]

A variation of 0.5 psi in differential pressure between air and electrolyte across the air cathode caused only a 1% change in cell potential at SC and at an air flow rate of 5.8 litre/min or 5.2 times stoichiometric. Electrolyte outlet differential pressure ranged 0.15 - 0.65 psi for cell 1 and 0.33 - 0.84 psi for cell 2. Thus, we may say that cathode performance is essentially unaffected by variations in differential pressure of 0 - 0.84 psi.

Pressure drop measured between electrolyte inlet and outlet probes is 0.45 psi. Hydraulic pressure head is calculated from Eq. (7) to be 0.44 psi. Thus, as in the case of

the M1-1 cell, the viscous pressure drop in the electrolyte caused by flowing up between electrodes is negligible (0.01 psi).

Air flow rate had little effect upon cell potential over a range of 2-12 times stoichiometric at SC and at an electrolyte outlet differential pressure of 0.5 psi for cell 2. Over this range, potential of cell 2 varied only 1.4%. As flow rate was decreased in cell 1, however, a condition of oxygen starvation ensued, as evidenced by a drop in cell potential. When air flow was decreased from 3.8 to 2.5 times stoichiometric, potential dropped 1.3%. Further decreasing the air to 2 times stoichiometric resulted in an unstable condition of potential oscillation, which has been observed previously.[3] This behavior implies an imbalance of air flow to the cells, a condition which can be corrected by separate air supply to each cell.

During the experiment, concentration of aluminate in the electrolyte increased 0.3 mole/litre, as shown by Table 2. Based on this value, it is calculated that 11% of the anode dissolved at an average current of 31 A over 161 min of testing. Total volume of electrolyte that weeped through the cathodes is 26 ml for cell 1 and 27 ml for cell 2.

CONCLUSIONS AND RECOMMENDATIONS

The rapidly-refuelable, 167-cm^2 aluminum-air cell was successfully tested as a single cell, and as a two-cell stack. The single cell was tested over a range of current density 0-5.2 kA/m^2, and its performance was essentially independent of air-electrolyte differential pressure across the air cathode, as well as of air flow rate. The reference electrode equivalent position was determined to be at the cathode, while its position for earlier 25- and 1000-cm^2 tests was at the anode. Maximum power density was 97% of that obtained earlier with the 25-cm^2 cell.

The two-cell stack behaved essentially the same as the single cell, and was tested over an extended current density range of 0-6.7 kA/m^2. Performance at high current surpassed earlier 25-cm^2 cell results. The stack was successfully operated with series and parallel electrical connection of cells.

The following are recommendations for changes in cell and test-stand designs for future testing: provide Luggin capillary reference-electrode electrolyte probes for measuring potentials of the working electrodes; provide separate air flow systems to each cell in the stack to allow individual differential pressure control; and reduce the ohmic potential drop in current collectors and external inter-cell electrical connection. In case the second recommendation above for separate air flow in not incorporated in future tests (perhaps in order to keep the control system simple), I recommend stacking no more than four cells together. This recommendation is based on an electrolyte pressure drop of 0.18 psi per cell and a hydrostatic pressure head of 0.23 psi. Assuming equal air and electrolyte pressures at the inlet of the first cell, the maximum differential pressure at the outlet of cell 4 would be 0.77 psi (3 x 0.18 + 0.23), a value safely within operating specifications of the cathode.

The LLNL rapidly-refuelable, 167-cm^2 design has proven to be an easy-to-manufacture, low-cost cell with which we have successfully demonstrated simplicity in replacing spent anodes, feasibility of internal electrolyte manifolding, and discharge of a multi-cell stack.

ACKNOWLEDGMENT

I thank Dr. John F. Cooper for his work in designing the M1-1 cell and Mr. B. Earl Kelly for work in designing, manufacturing, and testing both the M1-1 and M2-1 cells. Thanks also goes to Mr. B. J. McKinley for performing the required programming changes in the data collection system, and in assisting with the testing of the M2-1 cell.

APPENDIX A. OPERATING VARIABLES FOR THE SINGLE CELL, M1-1.

The following is a listing of the operating variables for the M1-1-3 experiment.

M1-1-3-1

TIME (HR:MIN)	I (A)	V(C-A) (V)	−V(C-R) (V)	−V(A-R) (V)	P IN (PSI)	−P OUT (PSI)	−P AV (PSI)
0: 1	-0.2	1.972	-0.168	1.794	-0.138	-0.100	-0.023
0: 4	-0.2	1.908	-0.092	1.815	0.148	-0.386	-0.265
0: 7	-0.2	1.894	-0.089	1.806	0.204	-0.448	-0.333
0: 10	-0.1	1.883	-0.085	1.798	0.192	-0.430	-0.309
0: 13	-0.1	1.874	-0.079	1.796	0.202	-0.437	-0.324
0: 15	-0.1	1.870	-0.076	1.794	0.273	-0.506	-0.387
0: 16	6.9	1.586	0.132	1.719	0.293	-0.534	-0.412
0: 18	7.6	1.602	0.114	1.716	0.310	-0.542	-0.423
0: 19	9.5	1.576	0.125	1.701	0.317	-0.555	-0.430
0: 21	10.1	1.586	0.122	1.709	0.345	-0.573	-0.455
0: 22	11.6	1.568	0.131	1.698	0.377	-0.610	-0.495
0: 22	14.4	1.540	0.143	1.682	0.381	-0.629	-0.507
0: 24	14.7	1.545	0.141	1.685	0.384	-0.627	-0.508
0: 24	19.7	1.490	0.162	1.652	0.379	-0.620	-0.510
0: 26	20.1	1.493	0.160	1.654	0.366	-0.596	-0.486
0: 26	24.5	1.446	0.177	1.624	0.378	-0.620	-0.502
0: 28	24.8	1.450	0.175	1.625	0.388	-0.625	-0.504
0: 28	30.8	1.392	0.195	1.587	0.380	-0.615	-0.500
0: 31	31.5	1.394	0.194	1.587	0.397	-0.642	-0.519
0: 32	39.7	1.313	0.221	1.534	0.390	-0.637	-0.522

0: 34	39.8	1.317	0.217	1.533	0.397	-0.627	-0.508
0: 35	45.0	1.269	0.232	1.501	0.397	-0.645	-0.524
0: 35	49.7	1.228	0.246	1.474	0.389	-0.623	-0.515
0: 35	54.5	1.183	0.260	1.443	0.397	-0.640	-0.521
0: 36	59.5	1.135	0.275	1.410	0.395	-0.634	-0.523
0: 36	64.6	1.087	0.289	1.375	0.416	-0.648	-0.523
0: 37	69.5	1.037	0.304	1.341	0.394	-0.631	-0.511
0: 37	74.5	0.986	0.321	1.307	0.397	-0.630	-0.514
0: 38	79.6	0.933	0.338	1.270	0.399	-0.638	-0.528
0: 39	84.8	0.890	0.355	1.246	0.395	-0.630	-0.513
0: 39	89.3	0.835	0.377	1.213	0.402	-0.632	-0.524
0: 40	85.1	0.885	0.350	1.235	0.395	-0.634	-0.513

M1-1-3-2, Differential Pressure and Air Flow Rate

TIME (HR:MIN)	I (A)	V(C-A) (V)	−V(C-R) (V)	−V(A-R) (V)	P IN (PSI)	−P OUT (PSI)	−P AV (PSI)
0: 41	31.0	1.431	0.169	1.600	0.403	-0.633	-0.512
0: 46	31.5	1.423	0.173	1.597	0.418	-0.649	-0.528
0: 47	31.6	1.425	0.174	1.599	0.356	-0.584	-0.468
0: 47	31.6	1.422	0.174	1.597	0.312	-0.542	-0.425
0: 48	31.5	1.419	0.176	1.595	0.281	-0.529	-0.410
0: 49	31.5	1.417	0.178	1.595	0.272	-0.500	-0.378
0: 49	31.5	1.416	0.180	1.596	0.257	-0.495	-0.376
0: 50	31.7	1.422	0.174	1.595	0.421	-0.649	-0.539
0: 50	31.6	1.420	0.174	1.594	0.421	-0.673	-0.561
0: 51	31.7	1.423	0.174	1.596	0.458	-0.694	-0.589
0: 53	31.7	1.419	0.175	1.593	0.554	-0.788	-0.674
0: 54	30.5	1.433	0.171	1.604	0.605	-0.842	-0.736

0: 55	30.5	1.429	0.173	1.602	0.691	-0.924	-0.802
0: 57	30.9	1.427	0.174	1.601	0.641	-0.876	-0.753
0: 58	30.9	1.424	0.173	1.597	0.342	-0.586	-0.472
1: 1	30.9	1.427	0.172	1.599	0.341	-0.577	-0.463

M1-1-3-3

TIME (HR:MIN)	I (A)	V(C-A) (V)	−V(C-R) (V)	−V(A-R) (V)	P IN (PSI)	−P OUT (PSI)	−P AV (PSI)
1: 1	9.8	1.671	0.083	1.753	0.346	-0.578	-0.465
1: 2	-0.1	1.885	-0.044	1.840	0.333	-0.573	-0.461
1: 2	9.2	1.678	0.081	1.759	0.349	-0.579	-0.464
1: 3	14.6	1.604	0.112	1.716	0.351	-0.589	-0.469
1: 3	19.8	1.546	0.134	1.679	0.343	-0.576	-0.458
1: 3	24.8	1.488	0.153	1.641	0.338	-0.578	-0.458
1: 4	29.9	1.429	0.170	1.601	0.347	-0.575	-0.459
1: 4	35.0	1.375	0.186	1.562	0.344	-0.569	-0.454
1: 4	39.8	1.325	0.202	1.526	0.350	-0.582	-0.465
1: 5	45.0	1.273	0.217	1.490	0.355	-0.589	-0.469
1: 5	50.1	1.228	0.232	1.460	0.348	-0.574	-0.454
1: 5	60.0	1.130	0.264	1.394	0.353	-0.577	-0.459
1: 6	65.0	1.078	0.280	1.358	0.349	-0.587	-0.473
1: 6	69.5	1.029	0.295	1.324	0.353	-0.588	-0.473
1: 7	74.5	0.969	0.315	1.284	0.340	-0.577	-0.463
1: 7	79.4	0.906	0.337	1.243	0.351	-0.577	-0.461
1: 8	84.1	0.840	0.367	1.208	0.365	-0.602	-0.476
1: 8	89.1	0.765	0.404	1.167	0.356	-0.583	-0.468
1: 11	89.3	0.762	0.394	1.156	0.355	-0.582	-0.465

1: 12	30.7	1.432	0.157	1.590	0.347	-0.579	-0.469
1: 17	31.8	1.427	0.164	1.591	0.348	-0.583	-0.472
1: 18	31.8	1.422	0.165	1.588	0.356	-0.588	-0.472

M1-1-3-4

TIME (HR:MIN)	I (A)	V(C-A) (V)	−V(C-R) (V)	−V(A-R) (V)	P IN (PSI)	−P OUT (PSI)	−P AV (PSI)
1: 19	-0.2	1.896	-0.053	1.843	0.342	-0.576	-0.464
1: 20	9.9	1.680	0.078	1.758	0.358	-0.591	-0.476
1: 20	20.0	1.552	0.129	1.680	0.364	-0.587	-0.471
1: 21	30.8	1.438	0.166	1.605	0.354	-0.592	-0.479
1: 21	39.8	1.345	0.193	1.538	0.349	-0.582	-0.465
1: 21	25.7	1.485	0.148	1.702	0.350	-0.583	-0.473
1: 22	50.1	1.234	0.225	1.459	0.357	-0.593	-0.476
1: 22	59.8	1.132	0.255	1.387	0.357	-0.586	-0.474
1: 22	69.6	1.021	0.290	1.311	0.351	-0.583	-0.466
1: 23	79.1	0.903	0.331	1.235	0.351	-0.584	-0.466
1: 23	89.3	0.752	0.397	1.147	0.354	-0.584	-0.468
1: 27	12.1	1.645	0.083	1.728	0.355	-0.583	-0.469

Shutdown

TIME (HR:MIN)	I (A)	V(C-A) (V)	-V(C-R) (V)	-V(A-R) (V)	P IN (PSI)	-P OUT (PSI)	-P AV (PSI)
1: 28	29.1	1.444	0.158	1.596	0.354	-0.600	-0.485
1: 29	31.3	1.427	0.162	1.589	0.356	-0.589	-0.477
1: 30	31.4	1.425	0.161	1.587	0.355	-0.589	-0.472
1: 31	31.4	1.423	0.162	1.586	0.412	-0.649	-0.531
1: 32	31.3	1.419	0.163	1.581	0.343	-0.582	-0.466
1: 33	31.3	1.416	0.164	1.579	0.340	-0.586	-0.461
1: 34	31.3	1.413	0.165	1.578	0.350	-0.582	-0.473
1: 35	31.2	1.410	0.165	1.576	0.368	-0.590	-0.475
1: 36	0.1	0.010	0.761	0.217	-0.002	0.003	0.006
1: 37	-0.1	0.004	-0.000	0.004	0.001	0.001	0.002
1: 38	-0.2	0.000	-0.281	-0.335	0.457	-0.663	-0.543
1: 39	-0.1	0.000	-0.360	-0.424	0.465	-0.677	-0.572
1: 40	-0.2	0.000	-0.363	-0.437	0.403	-0.614	-0.508
1: 41	-0.2	0.000	-0.203	-0.258	0.335	-0.543	-0.446
1: 42	-0.1	0.001	0.306	0.325	0.609	-0.809	-0.706
1: 43	-0.1	0.000	0.211	0.226	0.438	-0.651	-0.547
1: 44	-0.1	0.000	4.616	4.994	0.615	-0.799	-0.696
1: 45	-0.1	0.004	10.537	11.823	0.310	-0.472	-0.390
1: 46	-0.2	0.000	-0.053	-0.114	0.015	0.011	-0.004
1: 47	-0.2	0.000	-0.022	-0.107	0.036	-0.014	-0.026

APPENDIX B. OPERATING VARIABLES FOR THE TWO-CELL STACK, M2-1

The following is a listing of the operating variables for the M2-1-2 experiment. P IN and P OUT refer to the air-electrolyte differential pressure in cell 1 (ΔP_1) and in cell 2 (ΔP_2), respectively.

M2-1-2-1

TIME (HR:MIN)	I (A)	CELL 1 V(C-A) (V)	CELL 1 V(R-C) (V)	CELL 1 V(R-A) (V)	CELL 2 V(C-A) (V)	CELL 2 V(R-C) (V)	CELL 2 V(R-A) (V)	TOTAL V(C-A) (V)	P IN (PSI)	P OUT (PSI)
0: 0	-0.1	2.069	-0.166	1.894	-2.009	1.075	-0.158	2.654	-0.417	-0.403
0: 0	-0.1	2.008	0.256	2.280	1.997	-1.683	0.299	4.002	-0.086	0.050
0: 1	-0.1	1.958	0.712	2.670	1.985	-1.271	0.712	3.939	0.178	0.393
0: 1	-0.1	1.929	0.640	2.564	1.961	-1.349	0.609	3.888	0.186	0.401
0: 2	-0.1	1.899	0.693	2.600	1.940	-1.228	0.709	3.837	0.230	0.430
0: 2	-0.1	1.874	0.681	2.549	1.923	-1.232	0.689	3.796	0.307	0.497
0: 3	-0.1	1.861	0.698	2.549	1.911	-1.229	0.680	3.770	0.364	0.542
0: 3	-0.1	1.852	0.689	2.539	1.902	-1.221	0.685	3.753	0.356	0.541
0: 4	-0.1	1.844	0.701	2.542	1.893	-1.196	0.700	3.736	0.363	0.541
0: 4	-0.1	1.839	0.705	2.532	1.889	-1.196	0.693	3.728	0.369	0.555
0: 5	-0.1	1.832	0.689	2.527	1.883	-1.187	0.698	3.714	0.350	0.524
0: 6	-0.1	1.830	0.691	2.526	1.881	-1.195	0.688	3.711	0.305	0.478
0: 7	-0.1	1.825	0.690	2.513	1.877	-1.189	0.691	3.702	0.283	0.470
0: 8	-0.1	1.822	0.701	2.530	1.875	-1.175	0.698	3.697	0.314	0.488
0: 8	-0.1	1.822	0.691	2.515	1.873	-1.182	0.692	3.695	0.313	0.480
0: 9	-0.1	1.819	0.690	2.514	1.871	-1.174	0.697	3.690	0.313	0.488
0: 9	-0.1	1.817	0.705	2.523	1.868	-1.164	0.701	3.685	0.294	0.471
0: 10	-0.1	1.816	0.687	2.504	1.868	-1.175	0.694	3.684	0.253	0.452
0: 10	-0.1	1.815	0.697	2.513	1.867	-1.172	0.695	3.682	0.253	0.440

TIME (HR:MIN)	I (A)	CELL 1 V(C-A) (V)	CELL 1 V(R-C) (V)	CELL 1 V(R-A) (V)	CELL 2 V(C-A) (V)	CELL 2 V(R-C) (V)	CELL 2 V(R-A) (V)	TOTAL V(C-A) (V)	P IN (PSI)	P OUT (PSI)
0: 10	-0.1	1.813	0.698	2.508	1.866	-1.174	0.692	3.679	0.257	0.436
0: 11	-0.1	1.812	0.707	2.514	1.865	-1.167	0.697	3.677	0.263	0.438
0: 11	-0.1	1.811	0.705	2.516	1.864	-1.165	0.695	3.675	0.266	0.439
0: 12	-0.1	1.810	0.697	2.509	1.863	-1.163	0.702	3.673	0.265	0.452
0: 12	-0.1	1.809	0.693	2.503	1.862	-1.161	0.699	3.671	0.264	0.445
0: 12	-0.1	1.808	0.700	2.506	1.861	-1.165	0.696	3.669	0.272	0.446
0: 13	-0.1	1.806	0.697	2.499	1.859	-1.171	0.686	3.665	0.259	0.438
0: 14	-0.1	1.804	0.697	2.498	1.857	-1.159	0.697	3.660	0.269	0.443
0: 15	-0.1	1.802	0.697	2.508	1.855	-1.151	0.706	3.657	0.268	0.449
0: 16	-0.1	1.801	0.686	2.494	1.853	-1.152	0.703	3.654	0.268	0.444
0: 17	14.4	1.503	0.707	2.205	1.496	-0.767	0.730	2.969	0.271	0.447
0: 17	15.4	1.506	0.698	2.201	1.497	-0.778	0.714	2.971	0.267	0.434
0: 19	13.9	1.538	0.689	2.230	1.526	-0.801	0.721	3.033	0.266	0.433
0: 19	14.0	1.541	0.691	2.234	1.529	-0.815	0.714	3.038	0.262	0.428
0: 22	19.8	1.485	0.677	2.162	1.477	-0.756	0.720	2.921	0.260	0.434
0: 24	19.9	1.486	0.680	2.165	1.482	-0.760	0.723	2.926	0.269	0.436
0: 25	25.1	1.435	0.670	2.098	1.427	-0.706	0.722	2.808	0.271	0.443
0: 25	25.5	1.433	0.669	2.093	1.429	-0.714	0.713	2.809	0.272	0.441
0: 27	29.8	1.394	0.658	2.054	1.387	-0.660	0.725	2.718	0.289	0.460
0: 28	34.9	1.348	0.645	1.995	1.342	-0.619	0.722	2.615	0.287	0.458
0: 30	35.7	1.349	0.645	1.998	1.342	-0.617	0.727	2.614	*-0.159	*0.031
0: 33	40.0	1.306	0.640	1.951	1.306	-0.576	0.729	2.525	*-0.165	*0.010
0: 33	40.4	1.303	0.648	1.948	1.299	-0.581	0.723	2.515	*-0.174	*0.012
0: 36	45.3	1.257	0.630	1.882	1.254	-0.531	0.722	2.413	0.277	0.446
0: 36	45.9	1.259	0.619	1.878	1.239	-0.526	0.720	2.410	0.310	0.488

*ΔP_{in}

0: 37	50.1	1.223	0.607	1.828	1.203	-0.488	0.720	2.324	0.315	0.496
0: 40	55.3	1.175	0.595	1.769	1.159	-0.451	0.711	2.213	0.311	0.492
0: 42	60.0	1.133	0.578	1.710	1.114	-0.406	0.710	2.119	0.313	0.493
0: 44	65.1	1.083	0.560	1.646	1.059	-0.358	0.699	1.999	0.314	0.500
0: 45	69.8	1.040	0.551	1.591	1.014	-0.311	0.704	1.901	0.318	0.495
0: 47	75.1	0.997	0.536	1.532	0.965	-0.263	0.696	1.793	0.317	0.493
0: 47	75.2	0.996	0.536	1.532	0.966	-0.261	0.702	1.790	0.323	0.505
0: 48	79.6	0.952	0.522	1.474	0.914	-0.223	0.695	1.693	0.316	0.494
0: 49	79.8	0.951	0.518	1.469	0.915	-0.217	0.691	1.688	0.309	0.492
0: 51	85.1	0.898	0.505	1.403	0.858	-0.166	0.692	1.570	0.302	0.486
0: 55	90.7	0.855	0.478	1.334	0.793	-0.114	0.681	1.445	0.305	0.497
0: 58	35.5	1.371	0.657	2.027	1.368	-0.638	0.729	2.661	0.325	0.501
0: 58	30.3	1.424	0.672	2.098	1.424	-0.687	0.736	2.780	0.333	0.509
0: 59	24.8	1.481	0.686	2.168	1.484	-0.746	0.737	2.909	0.319	0.502
0: 60	19.7	1.535	0.693	2.230	1.536	-0.795	0.740	3.026	0.321	0.510
1: 0	15.3	1.590	0.712	2.300	1.589	-0.850	0.737	3.145	0.316	0.499
1: 1	-0.1	1.877	0.724	2.599	1.863	-1.147	0.715	3.742	0.317	0.491

M2-1-2-2

TIME (HR:MIN)	I (A)	V(C-A) (V)	CELL 1 V(R-C) (V)	V(R-A) (V)	V(C-A) (V)	CELL 2 V(R-C) (V)	V(R-A) (V)	TOTAL V(C-A) (V)	P IN (PSI)	P OUT (PSI)
1: 1	-0.1	1.885	0.710	2.599	1.872	-1.160	0.709	3.757	0.316	0.488
1: 4	15.4	1.568	0.701	2.266	1.559	-0.828	0.729	3.093	0.325	0.509
1: 5	20.2	1.512	0.666	2.180	1.504	-0.784	0.717	2.969	0.319	0.498
1: 5	30.3	1.403	0.649	2.052	1.389	-0.674	0.711	2.720	0.333	0.504
1: 6	40.9	1.296	0.619	1.914	1.273	-0.572	0.705	2.488	0.314	0.498
1: 6	50.7	1.207	0.594	1.801	1.185	-0.479	0.705	2.282	0.321	0.506
1: 6	60.7	1.117	0.567	1.683	1.089	-0.391	0.699	2.076	0.339	0.520

1: 7	70.5	1.034	0.543	1.577	0.994	-0.302	0.692	1.876	0.336	0.510
1: 7	80.2	0.940	0.511	1.452	0.889	-0.207	0.685	1.657	0.329	0.509
1: 7	90.0	0.838	0.481	1.319	0.775	-0.102	0.674	1.418	0.339	0.506
1: 8	80.2	0.936	0.510	1.446	0.888	-0.202	0.685	1.648	0.338	0.521
1: 8	80.5	0.937	0.510	1.447	0.888	-0.204	0.681	1.649	0.332	0.512
1: 9	70.6	1.032	0.541	1.573	1.002	-0.305	0.695	1.876	0.330	0.515
1: 9	60.6	1.125	0.569	1.694	1.105	-0.403	0.701	2.099	0.333	0.513
1: 9	49.9	1.226	0.612	1.838	1.211	-0.499	0.712	2.331	0.322	0.515
1: 10	40.6	1.315	0.632	1.948	1.310	-0.588	0.725	2.536	0.337	0.513
1: 10	30.6	1.417	0.666	2.085	1.415	-0.676	0.735	2.764	0.339	0.519
1: 10	20.5	1.529	0.695	2.228	1.528	-0.780	0.747	3.012	0.340	0.516
1: 11	14.9	1.597	0.718	2.312	1.597	-0.853	0.742	3.160	0.336	0.516
1: 11	15.0	1.596	0.706	2.301	1.596	-0.859	0.733	3.158	0.337	0.509
1: 11	15.0	1.597	0.707	2.303	1.595	-0.857	0.742	3.161	0.332	0.514
1: 12	15.0	1.597	0.705	2.297	1.596	-0.862	0.733	3.159	0.326	0.523
1: 12	15.0	1.595	0.702	2.297	1.593	-0.857	0.737	3.156	0.335	0.508

M2-1-2-3, Differential Pressure

TIME (HR:MIN)	I (A)	CELL 1 V(C-A) (V)	V(R-C) (V)	V(R-A) (V)	CELL 2 V(C-A) (V)	V(R-C) (V)	V(R-A) (V)	TOTAL V(C-A) (V)	P IN (PSI)	P OUT (PSI)
1: 14	32.0	1.404	0.651	2.057	1.397	-0.673	0.723	2.732	0.346	0.524
1: 17	31.4	1.412	0.652	2.060	1.406	-0.690	0.716	2.748	0.317	0.496
1: 18	31.2	1.408	0.657	2.070	1.400	-0.671	0.730	2.742	0.196	*-0.058
1: 19	31.3	1.408	0.663	2.070	1.399	-0.673	0.729	2.742	0.151	*-0.091
1: 20	31.3	1.407	0.654	2.062	1.399	-0.679	0.725	2.738	0.149	0.330
1: 21	31.2	1.410	0.661	2.070	1.402	-0.678	0.728	2.742	*-0.301	*-0.098

*ΔP_{in}

1: 22	31.2	1.410	0.654	2.067	1.381	-0.663	0.717	2.723	0.206	0.395
1: 23	31.4	1.411	0.653	2.067	1.387	-0.666	0.721	2.734	0.251	0.441
1: 24	31.5	1.405	0.658	2.063	1.398	-0.672	0.727	2.734	0.311	0.491
1: 25	31.5	1.406	0.661	2.066	1.398	-0.672	0.723	2.737	0.348	0.539
1: 26	31.6	1.406	0.663	2.068	1.397	-0.664	0.737	2.735	0.420	0.606
1: 27	31.6	1.403	0.659	2.064	1.400	-0.667	0.732	2.733	0.479	0.662
1: 28	31.6	1.403	0.658	2.060	1.403	-0.673	0.731	2.736	0.512	0.697
1: 29	31.6	1.401	0.662	2.061	1.399	-0.669	0.733	2.733	0.557	0.755
1: 30	31.7	1.404	0.658	2.064	1.402	-0.670	0.732	2.732	0.610	0.795
1: 31	31.7	1.403	0.660	2.063	1.396	-0.668	0.729	2.731	0.653	0.844
1: 32	31.7	1.402	0.658	2.063	1.399	-0.664	0.733	2.733	0.307	0.493

M2-1-2-4, Air Flow Rate

TIME (HR:MIN)	I (A)	CELL 1 V(C-A) (V)	CELL 1 V(R-C) (V)	CELL 1 V(R-A) (V)	CELL 2 V(C-A) (V)	CELL 2 V(R-C) (V)	CELL 2 V(R-A) (V)	TOTAL V(C-A) (V)	P IN (PSI)	P OUT (PSI)
1: 33	31.7	1.399	0.660	2.062	1.398	-0.662	0.734	2.729	0.313	0.483
1: 34	31.6	1.403	0.657	2.057	1.397	-0.672	0.724	2.733	0.304	0.494
1: 35	31.7	1.405	0.662	2.067	1.400	-0.667	0.733	2.734	0.317	0.505
1: 36	31.7	1.403	0.661	2.064	1.399	-0.673	0.722	2.733	0.305	0.513
1: 37	31.7	1.405	0.658	2.059	1.400	-0.676	0.723	2.736	0.325	0.502
1: 38	31.1	1.404	0.667	2.070	1.403	-0.670	0.734	2.739	0.308	0.491
1: 39	31.2	1.401	0.668	2.067	1.403	-0.671	0.733	2.734	0.294	0.484
1: 40	30.9	1.376	0.681	2.058	1.401	-0.646	0.757	2.711	0.296	0.488
1: 41	31.0	1.383	0.692	2.074	1.401	-0.649	0.750	2.719	0.296	0.480
1: 42	29.7	1.255	0.872	2.121	1.414	-0.480	0.935	2.590	0.295	0.481
1: 43	29.6	1.245	0.868	2.111	1.418	-0.481	0.939	2.592	0.293	0.481
1: 44	31.4	1.404	0.660	2.065	1.396	-0.681	0.716	2.734	0.290	0.476

1: 45	31.4	1.410	0.647	2.057	1.397	-0.678	0.720	2.738	0.311	0.493
1: 46	31.5	1.413	0.650	2.063	1.396	-0.680	0.715	2.743	0.317	0.502
1: 47	31.5	1.412	0.643	2.054	1.398	-0.688	0.712	2.740	0.337	0.518
1: 48	31.6	1.413	0.651	2.064	1.399	-0.683	0.717	2.742	0.341	0.516

M2-1-2-5

TIME (HR:MIN)	I (A)	CELL 1 V(C-A) (V)	CELL 1 V(R-C) (V)	CELL 1 V(R-A) (V)	CELL 2 V(C-A) (V)	CELL 2 V(R-C) (V)	CELL 2 V(R-A) (V)	TOTAL V(C-A) (V)	P IN (PSI)	P OUT (PSI)
1: 51	31.4	1.412	0.654	2.065	1.398	-0.678	0.723	2.744	0.327	0.511
1: 51	20.3	1.534	0.684	2.218	1.522	-0.796	0.725	3.014	0.342	0.517
1: 52	15.7	1.592	0.698	2.290	1.583	-0.849	0.733	3.140	0.334	0.521
1: 52	-0.1	1.884	0.713	2.597	1.877	-1.165	0.710	3.762	0.328	0.512
1: 52	15.7	1.591	0.701	2.2?4	1.582	-0.847	0.737	3.140	0.339	0.512
1: 53	20.6	1.532	0.683	2.215	1.523	-0.793	0.729	3.010	0.343	0.514
1: 53	30.2	1.425	0.653	2.077	1.410	-0.695	0.714	2.768	0.332	0.527
1: 54	40.6	1.320	0.626	1.942	1.298	-0.588	0.707	2.529	0.338	0.509
1: 54	50.3	1.221	0.609	1.828	1.195	-0.484	0.707	2.304	0.342	0.532
1: 54	60.5	1.123	0.569	1.691	1.086	-0.391	0.695	2.075	0.341	0.512
1: 55	70.5	1.024	0.544	1.566	0.982	-0.285	0.697	1.850	0.342	0.540
1: 55	80.4	0.922	0.512	1.436	0.877	-0.185	0.687	1.615	0.353	0.536
1: 56	90.2	0.814	0.484	1.295	0.763	-0.087	0.674	1.375	0.334	0.528
1: 56	74.5	0.985	0.533	1.537	0.985	-0.298	0.693	1.914	0.347	0.526
1: 56	50.6	1.210	0.603	1.810	1.188	-0.489	0.695	2.285	0.347	0.536
1: 57	17.0	1.566	0.698	2.263	1.560	-0.815	0.744	3.090	0.338	0.537

M2-1-2-6

TIME (HR:MIN)	I (A)	CELL 1 V(C-A) (V)	CELL 1 V(R-C) (V)	CELL 1 V(R-A) (V)	CELL 2 V(C-A) (V)	CELL 2 V(R-C) (V)	CELL 2 V(R-A) (V)	TOTAL V(C-A) (V)	P IN (PSI)	P OUT (PSI)
2: 1	17.3	1.565	0.695	2.258	1.554	-0.825	0.728	3.081	0.319	0.498
2: 2	-0.1	1.878	0.705	2.586	1.866	-1.162	0.704	3.745	0.316	0.502
2: 3	16.8	1.572	0.693	2.266	1.560	-0.829	0.733	3.095	0.388	0.555
2: 4	20.5	1.523	0.674	2.195	1.511	-0.794	0.719	2.988	0.386	0.544
2: 4	30.1	1.417	0.649	2.067	1.397	-0.688	0.707	2.748	0.381	0.532
2: 4	40.4	1.315	0.614	1.930	1.290	-0.585	0.710	2.517	0.381	0.554
2: 5	50.5	1.215	0.588	1.806	1.187	-0.487	0.699	2.291	0.384	0.552
2: 5	60.2	1.126	0.567	1.692	1.086	-0.390	0.698	2.081	0.399	0.562
2: 6	70.3	1.031	0.536	1.567	0.987	-0.298	0.687	1.862	0.397	0.562
2: 6	80.2	0.938	0.509	1.446	0.881	-0.198	0.684	1.643	0.410	0.574
2: 7	89.9	0.843	0.477	1.319	0.776	-0.099	0.675	1.422	0.400	0.563
2: 8	99.9	0.747	0.445	1.194	0.668	-0.001	0.665	1.197	0.401	0.575
2: 8	104.9	0.688	0.427	1.117	0.606	0.054	0.657	1.066	0.410	0.573
2: 8	109.3	0.626	0.409	1.033	0.542	0.110	0.650	0.922	0.406	0.580
2: 9	114.9	0.562	0.389	0.953	0.473	0.170	0.643	0.781	0.398	0.570
2: 10	116.5	0.546	0.380	0.926	0.450	0.188	0.639	0.734	0.396	0.577
2: 10	110.0	0.612	0.400	1.013	0.523	0.123	0.644	0.892	0.408	0.583
2: 11	100.5	0.712	0.433	1.144	0.635	0.020	0.659	1.121	0.405	0.586
2: 11	90.5	0.823	0.467	1.289	0.753	-0.084	0.671	1.374	0.409	0.576
2: 11	80.4	0.918	0.500	1.417	0.866	-0.186	0.679	1.602	0.416	0.578
2: 12	70.2	1.008	0.527	1.535	0.966	-0.283	0.683	1.818	0.415	0.585
2: 12	29.9	1.406	0.657	2.064	1.395	-0.669	0.727	2.734	0.412	0.581
2: 13	20.3	1.515	0.699	2.212	1.507	-0.778	0.731	2.979	0.398	0.580

2: 13	16.0	1.572	0.706	2.281	1.565	-0.823	0.743	3.100	0.428	0.592
2: 14	-0.1	1.893	0.713	2.607	1.878	-1.167	0.710	3.771	0.397	0.571
2: 14	16.3	1.573	0.694	2.270	1.566	-0.832	0.732	3.100	0.413	0.580
2: 16	-0.1	1.865	0.720	2.579	1.853	-1.152	0.700	3.725	0.388	0.556

M2-1-2-7, Parallel Electrical Connection

TIME (HR:MIN)	I (A)	CELL 1 V(C-A) (V)	CELL 1 V(R-C) (V)	CELL 1 V(R-A) (V)	CELL 2 V(C-A) (V)	CELL 2 V(R-C) (V)	CELL 2 V(R-A) (V)	TOTAL V(C-A) (V)	P IN (PSI)	P OUT (PSI)
2: 17	-0.1	1.893	-0.039	1.853	1.879	-0.017	1.863	1.870	0.397	0.552
2: 18	-0.1	1.893	-0.039	1.853	1.880	-0.019	1.860	1.874	0.394	0.545
2: 18	-0.1	1.891	-0.042	1.849	1.879	-0.019	1.860	1.868	0.380	0.546
2: 20	-0.1	1.878	-0.032	1.846	1.878	-0.032	1.845	1.878	0.386	0.546
2: 21	-0.1	1.872	-0.032	1.840	1.871	-0.032	1.840	1.871	0.338	0.499
2: 21	5.8	1.741	0.049	1.790	1.741	0.049	1.791	1.741	0.347	0.500
2: 22	27.4	1.575	0.097	1.671	1.574	0.097	1.669	1.573	0.354	0.509
2: 22	30.6	1.549	0.101	1.651	1.549	0.102	1.651	1.548	0.333	0.507
2: 23	40.7	1.486	0.115	1.603	1.490	0.115	1.603	1.487	0.349	0.510
2: 23	50.5	1.429	0.127	1.555	1.429	0.127	1.556	1.429	0.338	0.487
2: 24	60.6	1.377	0.137	1.515	1.374	0.138	1.514	1.376	0.359	0.501
2: 24	70.6	1.330	0.146	1.477	1.329	0.148	1.478	1.328	0.357	0.519
2: 24	74.6	1.314	0.151	1.465	1.312	0.153	1.466	1.311	0.352	0.535
2: 25	80.5	1.287	0.156	1.442	1.285	0.158	1.444	1.285	0.353	0.526
2: 25	90.7	1.234	0.166	1.399	1.232	0.169	1.401	1.231	0.358	0.522
2: 26	100.6	1.186	0.176	1.363	1.187	0.178	1.364	1.185	0.371	0.522
2: 26	120.4	1.091	0.194	1.283	1.089	0.197	1.286	1.088	0.349	0.509
2: 27	129.5	1.040	0.205	1.246	1.039	0.206	1.246	1.039	0.357	0.519
2: 27	140.4	0.988	0.212	1.201	0.985	0.216	1.202	0.985	0.361	0.525

TIME (HR:MIN)	I (A)	V(C-A) (V)	CELL 1 V(R-C) (V)	V(R-A) (V)	V(C-A) (V)	CELL 2 V(R-C) (V)	V(R-A) (V)	TOTAL V(C-A) (V)	P IN (PSI)	P OUT (PSI)
2: 27	150.1	0.944	0.222	1.165	0.940	0.226	1.166	0.939	0.366	0.521
2: 28	158.3	0.894	0.230	1.122	0.888	0.234	1.122	0.890	0.355	0.517
2: 30	30.1	1.578	0.110	1.687	1.578	0.110	1.687	1.575	0.375	0.533
2: 30	25.0	1.615	0.099	1.714	1.613	0.099	1.713	1.614	0.364	0.540
2: 30	20.1	1.651	0.089	1.739	1.651	0.089	1.740	1.651	0.349	0.516
2: 31	15.1	1.689	0.077	1.767	1.690	0.078	1.766	1.689	0.370	0.533
2: 31	10.4	1.728	0.060	1.788	1.728	0.060	1.788	1.727	0.363	0.525
2: 32	7.2	1.758	0.049	1.808	1.758	0.050	1.808	1.758	0.361	0.524
2: 32	-0.1	1.888	-0.028	1.861	1.888	-0.028	1.860	1.889	0.352	0.525

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INDUCTIVE POWER TRANSFER FOR PROPULSION
A Status Report

Carl E. Walter

TRANSPORTATION SYSTEMS RESEARCH

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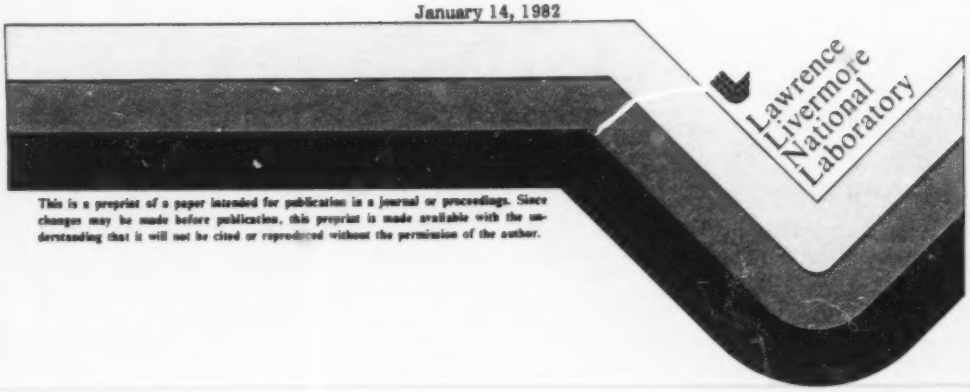

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INDUCTIVE POWER TRANSFER FOR PROPULSION
A Status Report

ABSTRACT*

Application of the concept of inductive power transfer to propulsion of buses, automobiles, and trucks can contribute to a quality national transportation system. The concept is basically an air gap transformer which inductively couples the primary in the roadway to the secondary suspended beneath the vehicle. Power is transferred efficiently in this manner and can be used in an electric motor for propulsion. The concept originated nearly 100 years ago, but only recently received attention as a means of providing quality highway transportation with little visual and audible presence, no noxious fumes, and without dedicated use constraints. Implementation of this concept could reduce the present, nearly complete dependence of transportation on petroleum.

Current investigations include a detailed experimental program, evaluation of the impact on electrical utility generating capacity and early applications in transit. Progress has been slowed by federal government funding limitations; future progress will be impeded unless new support is forthcoming.

INTRODUCTION

Unavailability of petroleum is a serious situation threatening our country's transportation systems and the well-being of our society. Certainly a petroleum shortage is an issue that should rank high in a list of critical issues facing our nation's transportation system. Transportation is a major factor which determines our way of life. A quality transportation system provides high mobility at low cost with comfort and safety. This implies tailored modes of transportation for specific situations which are quiet and cause minimal air pollution. To maintain high mobility at low cost it is important to utilize energy efficient propulsion systems, and in this age also reduce our heavy dependence on petroleum.

The U.S. transportation sector is currently almost totally dependent on petroleum, 40% of which is imported. Moreover, transportation accounts for half of the total U.S. petroleum consumption. A small disruption of imports can have a severe effect on both personal and commercial transportation, as the gas lines of 1973 and 1979 gave evidence.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

While some adjustment to a reduced gasoline supply is possible, higher prices and reduced mobility will have a most deleterious effect on the nation's economy. A disruption of imports can occur at anytime, and presently there are no alternatives commercially available. Therefore, alternatives should be developed and put into wide-spread use as soon as possible to ameliorate the consequences of a disruption of our petroleum supply.

In the longer term, the rapid depletion of U.S. and world petroleum resources points to the need for alternatives in any case. It is generally agreed that world resources of petroleum will become increasingly more expensive to produce as the remaining resources become more inaccessible. This will necessarily lead to a reduced demand for oil inspite of a continuing need for adequate transportation. The situation is further exacerbated by an increasing world population and entry of the developing nations into competition for oil. Serious oil shortages could almost certainly occur shortly after the turn of the century if not before.

This paper discusses an old but heretofore unused propulsion concept suitable for mixed use by automobiles, trucks, and buses. The inductive power transfer concept is not dependent on petroleum and thus provides a means for avoiding a serious crisis. Electric vehicles drawing power inductively from the roadway can contribute to a quality transportation system. Powered roadways can be used interchangeably and simultaneously by buses, trucks, and automobiles whether or not they are equipped to take energy from the roadway. It is anticipated that development of powered roadways will be spearheaded by transit since in this application both the roadway and the vehicles are publicly owned. With the roadway in place through the efforts of transit properties, private users will be motivated to purchase automobiles and trucks which can beneficially take power from the roadway. Indeed, the transit system should be able to amortize roadway costs over the wider base including private users.

The concept of inductive power transfer to a moving vehicle is being investigated at the Lawrence Livermore National Laboratory (LLNL) under the Roadway Powered Electric Vehicle (RPEV) Project.

POWERED ROADWAY CONCEPT

For maximum flexibility in utilizing inductive power transfer for propulsion, the vehicle should have an alternative means of propulsion. This allows for continued operation away from the powered roadway and for lane changing to pass slower vehicles.

Figure 1 depicts an automobile over a powered roadway with batteries for alternative propulsion. Buses might use flywheels or batteries. Automobiles and trucks could also use an internal combustion engine for alternative propulsion.

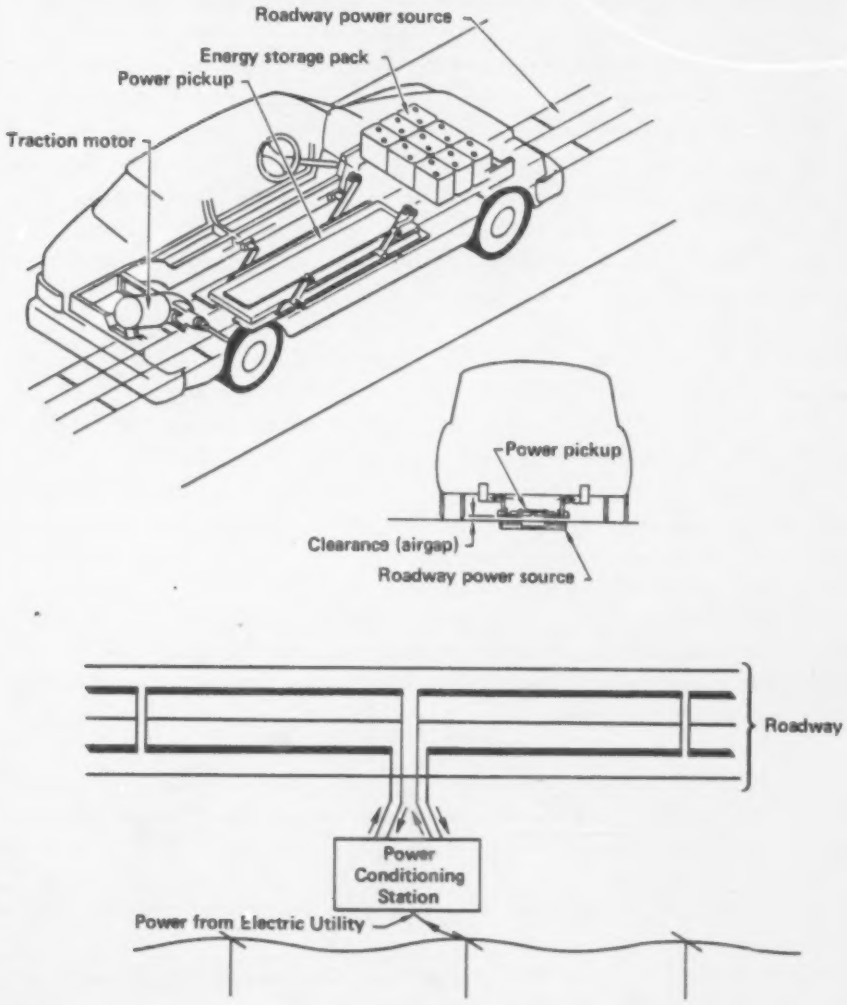


Fig. 1. Powered roadway system.

The automobile in Fig. 1 has a coil suitably wrapped around a transformer steel core suspended beneath the vehicle, a short distance above the surface of the roadway. There is no mechanical contact between this power pickup and the road. The energy source is immediately beneath the surface. It consists of insulated conductors colineal with the direction of travel and lying in a trough made of transformer steel. In practice, these components need not be visible; a display on the driver's instrument panel would indicate the location of the power components in the road. Automatic steering could also be provided. The relatively high alternating current in the conductors produces an alternating magnetic field which couples inductively with the vehicle's power pickup.

Power for the roadway would be derived from a nearby transmission line as indicated in Fig. 1. Power conditioning stations would be positioned at appropriate intervals along the powered roadway. High-voltage 60-Hz power from the transmission line would be conditioned to a higher frequency and maintained at a constant current in the roadway.

This concept promises to provide quality highway transportation which has little or no visual presence or noxious fumes and does not depend strongly on petroleum availability. Unsightly overhead power lines and troublesome "third" rails could be avoided by "trolley" buses and light rail systems. The noise and stench from diesel buses could also be avoided.

HISTORY

The concept of inductive coupling was patented as early as the 1890's both in the United States (1891) and in England (1895) shortly after the invention of alternating current (1881) and transformers (1886). More recent patents were issued in the United States in 1975 and 1977. The Department of Energy (then ERDA) became interested in the concept of inductive power transfer as a means of extending the range of electric vehicles. In 1976 the Lawrence Berkeley Laboratory (LBL) was assigned to perform a feasibility study.

The results published by Bolger and Kirsten[1] indicate that an inductively coupled energy system could provide an efficient means of propulsion, would be compatible with several vehicle types, environmentally acceptable, accommodating of operator skill variation, and result in no additional highway driving hazards. Further experimental investigations were warranted.

Subsequent efforts at LBL investigated various roadway power system designs, emphasizing trade-offs involved in design optimization. Based on these efforts, a prototype inductive energy transfer system was designed and static tests were conducted.

The results obtained by Bolger, et al[2] from the static tests demonstrate the predictability and efficiency of inductive energy transfer. The next step in the investigation was to determine performance characteristics under dynamic operating conditions. The work begun at LBL was moved to LLNL in 1979, where dynamic tests and application analyses are being conducted as part of the RPEV project.

The RPEV project is currently sponsored by the Department of Energy and the California Department of Transportation (Caltrans). Past support has been provided by the Federal Highway Administration, the Urban Mass Transit Administration, and the Research and Special Programs Administration of the Department of Transportation. This broad sponsorship is appropriate and necessary since highway construction and maintenance as well as mass transit are the responsibility of federal, state, and local transportation departments. It is desireable for other state and local agency transportation departments to sponsor development of this concept in the future.

PRESENT PROJECT AT LLNL

The present project at LLNL is focused in two areas. First, we are in the process of conducting tests of the roadway with a moving vehicle. Second, we are investigating the impact on electrical utility generating capacity of wide scale deployment of powered roadways. The latter study is of importance only if a large number of automobiles in a local area are postulated to be powered from the roadway. For mass transit, this impact on electrical utilities would probably not be significant.

The dynamic tests are conducted on a 220-m long test track with a 50-m powered section. The track is concrete 3.7 m wide. The roadway power system is shown schematically in Fig. 2. A motor-generator provides constant current to the roadway at several preselected discrete frequencies. By changing pulleys in the pulley/belt drive between the motor and the generator, output frequency can be varied between 150 an 400 Hz. A variable capacitor bank is connected in parallel with the roadway conductors across the generator. In this manner the highly inductive conductors can be tuned to provide a high system power factor. Current is maintained at the desired value, around 1000 A, by controlling the voltage on the generator field winding.

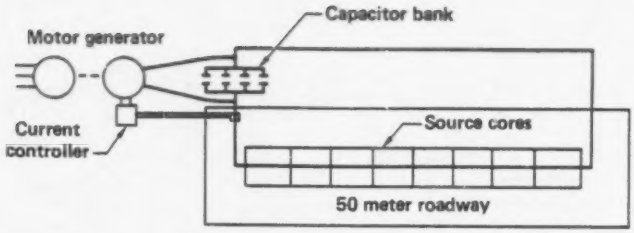


Fig. 2. Schematic design of roadway power components.

The magnetic core is of the same design as those used in the LBL static tests. A sectional view of the test installation is shown in Fig. 3. Core sections about 0.75 m in length are laid in a concrete slot formed in the roadway. The height of each core section is adjusted to bring the steel laminations within 3 mm below the surface of the roadway. The roadway conductor consists of six insulated stranded aluminum cables, connected in parallel and placed in the central trough formed by the steel core. The cross-sectional area of aluminum is 30 cm^2. A special cable made from insulated, braided strands and formed into a flat rectangular shape would probably be used in a service application. For operational convenience, the cores and cables are covered with easily removable Monterey sand and rubber runners. The actual installation is shown in Fig. 4.

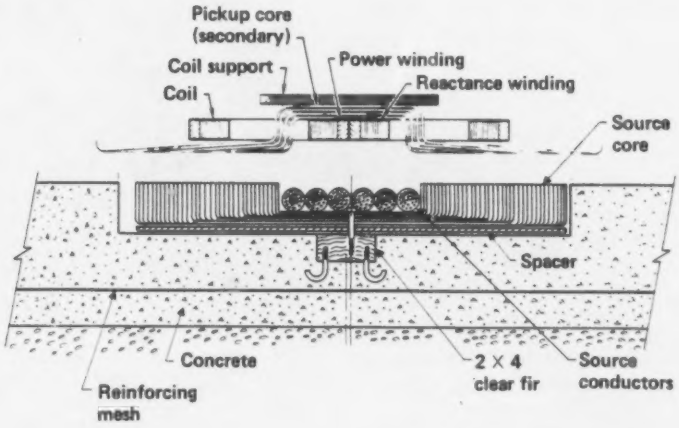
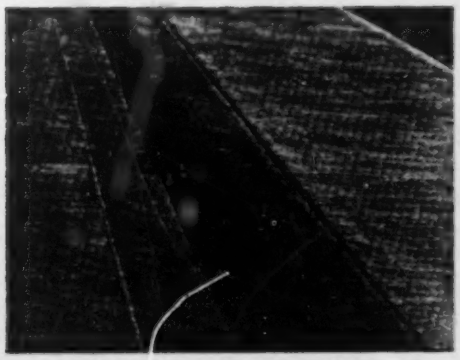
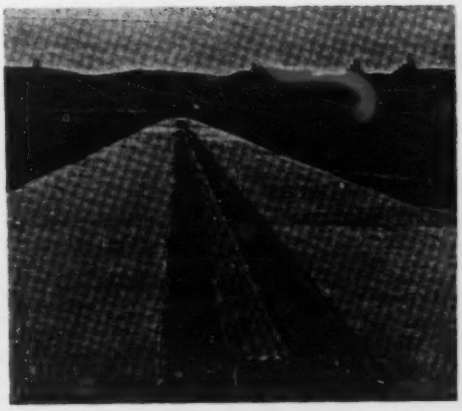


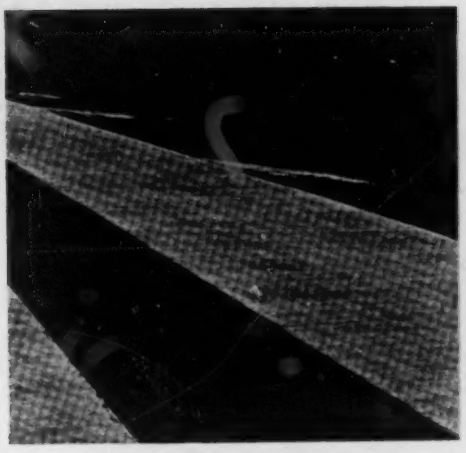
Fig. 3. Sectional view showing source core and conductor installation.

(b)





(a)



(c)

Fig. 4. Photograph (a) is an overall view of the powered section with magnetic cores, aluminum cables, and Monterey sand in place. Photograph (b) is a close-up view showing rubber runner in place over the cables. Photograph (c) shows the overall rubber runner in place.

The test vehicle shown in Fig. 5 is a modified 1969 Volkswagen. The body and engine were removed, and a sturdy frame was built around the remaining chassis components. The vehicle is equipped with a 6 kW compound-wound dc-traction motor, a transistorized controller, and six 12-V traction batteries. A hand-operated pickup suspension system is used to raise and lower the power pickup. Space is provided for instrumentation. A rectifier and a variable capacitance bank used in the power pickup circuit are also on the chassis.

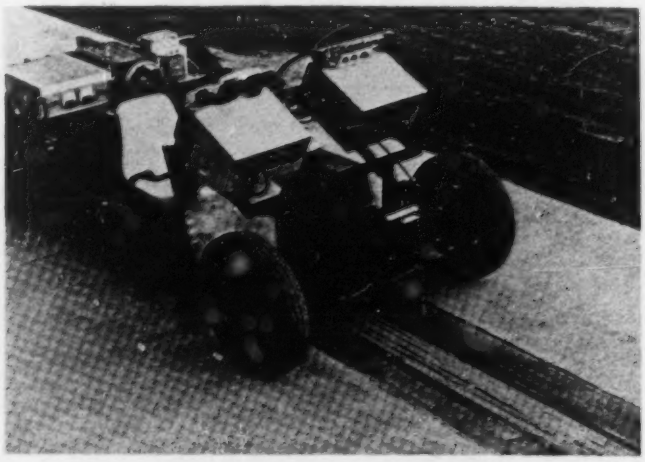


Fig. 5. Right front view of the powered roadway test vehicle.

The power pickup suspended under the test vehicle has a cross section similar to that used in the earlier LBL tests. Its coil windings, however, are made of aluminum instead of copper to reduce weight and the magnetic core is twice as long and is made in two sections. With roadway power at a lower frequency (180 kW), both sections are needed to obtain about 16 kW of power. At higher frequency, ~300 Hz, one section will provide the same power. The windings form two coils. One coil is connected to the capacitance bank which is adjustable, by manual switching, to compensate for changing coupling characteristics caused by variations in air gap and lateral offsets. Ultimately, an automatic switching circuit would be employed. The second coil is connected to the rectifier and its output is further smoothed by an inductor.

To date, only cursory experiments have been conducted on the test track. The test vehicle was operated for the first time with power from the roadway on April 22, 1981. Experimental progress has been slowed by lack of funds. Completion of the necessary instrumentation is imminent and we anticipate commencement of instrumented tests in the following areas early in 1982.

- System characteristics
- Power coupling capacity
- Vehicle performance
- Roadway compatibility

The system characteristics tests series provides a description of the magnetic, electrical, thermal, acoustic, and physical features of the dynamic test system. Some of these characteristics have been reported by Salisbury, et al.[3] The power coupling capacity test series will be conducted to determine the peak power capability of the powered roadway/vehicle system. The vehicle performance test measures the vehicular steering/ride/performance characteristics off and on the powered roadway and during engagement and disengagement from the powered roadway. Qualitatively, we have not noted any adverse effects under these conditions. The roadway compatibility test allows estimates of the operational and environmental differences caused by application of power to a roadway. For example, some have expressed concern about eddy current heating of conducting materials near the roadway. We have measured maximum temperature increases of only 8°C in the gas tank (1/4 full) of a 1980 Citation and 15°C in its rear axle with the car standing over the powered test track.

The roadway/vehicle electrical circuit has been analyzed in considerable detail to guide preparations for the experimental program. The results of these analyses were published by Salisbury and Walter.[4] The salient results are:

- Pickup efficiency during normal operation is above 90%.
- System efficiency (for the test configuration) is over 80%.
- Higher frequency operation allows reduction of pickup size, and reactance.
- Air gap can be increased without substantial reduction in efficiency.

The objective of the application analysis effort is to determine the impact of wide scale deployment of RPEV on the generating capacity of electric utilities and to assess the potential for petroleum savings. Powered roadways would be in use during peak utility

loading periods as well as during off peak periods. How this added load affects the utility's operation is of concern. Since peaking power is often provided by burning petroleum fuels, it is not a straight forward calculation to determine the amount of petroleum which is saved by replacing internal combustion engine powered vehicles.

OTHER ACTIVITIES

Besides supporting the activities at LLNL, Caltrans has initiated a project to demonstrate the operation of a modified Electrobus on a quarter-mile powered street in Berkeley, CA. A principal contractor to Caltrans in this effort is Inductran Corporation. The Caltrans Transportation Laboratory is developing methods of installing power components in the roadway. The survivability of these components will be determined from sample installations subjected to daily traffic at their Laboratory.

Howard Ross Associates has performed a study to investigate the application of a system of small electric buses using inductive power transfer in downtown Santa Barbara, CA.[5] The Phase I (feasibility) study was carried out for the Santa Barbara Metropolitan Transit district with State of California funds. Subsequent phases are: Phase 2, (in progress) Planning and Engineering; Phase 3, Prototype and Testing; Phase 4, Fabrication, Construction and Shakedown, and Phase 5, Revenue Operation. Overall plans are directed toward initial revenue operation beginning in 1984.

Howard Ross Associates has also prepared a number of proposals to perform preliminary feasibility studies for freeway transit electrification projects. These are in various states of review at local, state, and federal levels.

Additional activities are being carried out for the private sector by Inductran Corporation. Current contracts in addition to the work for Caltrans already mentioned involve low power dynamic systems and higher power static (battery charging) systems. Company sponsored studies are underway of people mover, warehousing, and burden carrying applications.

The formation of Inductran Corporation and the active promotion of Howard Ross Associates herald the commercialization of inductive energy transfer technology. Active local, state, and federal participation and leadership is imperative, however, since public roadways are utlimately involved.

ISSUES TO BE RESOLVED

Performance characteristics of inductive power transfer for propulsion are predicted to be attractive. The dynamic tests at LLNL are expected to corroborate these predictions and the application analyses study will identify impacts on the electric utilities and the potential for petroleum savings. In the meantime, the real world applications being carried out by industry may begin to develop the pragmatic aspects of inductive power transfer.

We have identified additional issues which must be resolved. These issues are listed below:

1. RPEV compatibility with conventional transportation
2. Cost/benefit comparison with alternate systems
3. Effect of RPEV on prosthetic devices
4. Electrical safety characteristics
5. Feasibility, compatibility with automatic control
6. Likely regions for implementation
7. Effect of climate and weather
8. Optimum operating conditions and component designs
9. Necessary or desirable subsidies & incentives
10. Billing methods for powered roadway users
11. Off-roadway alternative propulsion systems
12. Physiological effects
13. Implementation strategy
14. Market penetration

Many of these issues can be resolved by constructing a powered roadway network in a controlled area, such as a government installation. In this way, beneficial transportation functions could be performed while competing power component designs are evaluated on a large scale. About five to ten lane-miles would be an appropriate size. Necessary traffic interruptions would not affect the public at large. Construction experience to differing specifications would be obtained and a basis for standardization could be established.

IN CONCLUSION

The use of alternative fuels for transportation will reduce our dependence on petroleum. Synthetic fuels derived from coal or bio-mass are one alternative which cannot be ignored. However, one cannot, ipso facto, consider synfuels a viable alternative. The electric vehicle provides another means of using alternative fuels, since only a small fraction (14%) of U.S. electricity is generated by means of burning petroleum.

Electric vehicles at present have limited range and this feature impacts adversely on their popularity and thereby limits their use. This limitation can be alleviated by developing better batteries for electric vehicles, battery/gasoline hybrid vehicles, or systems which make it possible to obtain electricity from an external source as a vehicle travels. One way to accomplish this goal may well be to install powered roadways. RPEVs provide "unlimited" range on powered roadways and a limited capability away from the powered roadway.

A test track and vehicle for experimentally determining the operating characteristics of the system are available. The first operation of this test system was in April when our vehicle was propelled with energy transferred from the roadway. Instrumentation required for the dynamic test program is being completed in preparation for making the experimental measurements.

A study has been initiated to determine the impact on electric generating capacity and the potential petroleum savings for wide scale implementation of RPEV. Additional issues have been identified which need to be resolved, but the basic concept appears to be viable. Beyond the work in progress it will be necessary among other tasks to optimize system and component parameters, evaluate roadway and vehicle costs, and identify the best regions for early application.

In the face of the large federal budget deficit, funding support for powered roadway investigations has been drastically reduced. Yet, this research and development effort is vital to providing options for reducing our nation's dependence on petroleum. State governments need to be deeply involved now in the development of technologies which ultimately could become a critical component of public thoroughfares. A cooperative program funded by the states and the Federal government can be tailored to meet specific state needs and is inherently more user-oriented. Such a program would be in the best interests of the nation.

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STATEMENT BY

LEAD INDUSTRIES ASSOCIATION, INC.

FOR THE HEARING OF THE

SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION

OF THE

SCIENCE AND TECHNOLOGY COMMITTEE

DECEMBER 8, 1981

Executive Summary

America's energy problems could be solved quite handily if the nation curtailed its consumption of petroleum in favor of utilizing more readily available energy resources such as coal, nuclear power and solar energy. Unfortunately, there is a missing link in the equation. Coal, nuclear and solar do not lend themselves well toward powering America's largest consumer of energy -- the internal combustion engine. They are, however, prime sources of electrical power. What is needed, therefore, to complete this nation's energy turnaround is a system capable of efficiently storing the electricity produced by such resources -- a system that could provide electricity wherever and whenever it is needed.

Lead Industries Association (LIA) believes that the lead acid battery is ready to take its place as the storage link on an energy chain that could help reduce America's dependence on foreign oil. Thousands of lead battery-powered vehicles are already on the nation's roads, conserving their share of petroleum. Lead batteries are also at the forefront of the solar boom, helping to store photovoltaic energy for use when the sun is not shining -- another savings of crude oil. And, most importantly, lead batteries form the heart of a test project which has indicated that energy storage systems can be used to markedly increase the efficiency of electric generating plants, whether they be powered by coal, nuclear, hydro or oil. Until recently, the Federal Government has helped fund research and development in these three emerging areas. But despite the impressive R & D gains achieved -- including a 39% improvement in lead acid battery performance -- the funding has dried up. LIA believes now is the time to renew Federal grants to battery R & D, thereby renewing America's commitment to energy independence.

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Introduction

There is no energy shortage in this country. The United States is situated on coal reserves of such magnitude that it is estimated that the deposits can meet our energy demands for the next 500 years. However, the nation does face a critical energy problem, caused by our over dependence on petroleum, which has evolved as the most popular energy source for transportation. A solution might be to replace oil with coal in the transportation sector, but at our present level of technology, a chunk of coal cannot be utilized directly to power a car, truck, bus, or diesel locomotive.

Coal does have a place in the nation's current energy network, however. It can be burned cleanly and efficiently to power our existing electrical generating facilities. The challenge lies in putting these coal-produced watts to work to decrease our dependence on petroleum.

The solution proposed by Lead Industries Association (LIA) is the increased development and use of lead acid batteries to store electrical power so that it is readily available when needed. LIA's proposal is three-pronged, involving the implementation of: 1) Battery-powered electric vehicles which would be charged during off-peak hours, thus better utilizing the nation's electric generating capacity, whether the plants be coal, nuclear or hydro powered; 2) Electric utility load leveling, whereby batteries would store off-peak energy for release during prime periods of consumption; 3) Solar energy storage, in which batteries would capture the electricity produced by photovoltaic collectors, storing it for use as needed.

The significant aspect of LIA's three-point plan is that it recognizes that the nation's reliance on systems powered by petroleum cannot be replaced overnight, or even over a decade. The technologies discussed in the LIA proposal are designed to conserve the liquid fuel so that it is available for applications that truly require petroleum based energy. LIA's suggestions are grounded firmly on technological and economic realities.

As far as the proposed technologies themselves are concerned, each has an in-use track record, which indicates its potential for growth.

Battery Powered Electric Vehicles in the Transportation System

Electric vehicles are a viable means of transportation today. To cite just a few current applications, battery-powered vans are in operation with the U.S. Postal Service; electric buses are transporting passengers around Roosevelt Island in New York City, and in Washington, D.C., electrics are playing an important role with the National Park Service.

The electric vehicle was not conceived, nor is it proposed, as a replacement for all internal combustion carriers. It is intended to be used for short-range people and cargo moving. As such, the EV is ideal for fixed route, multiple stop delivery operations, or for use as the family's primary car for commuting, shopping, and other tasks in the urban-suburban centers of our nation. The latter application is particularly meaningful since it has been estimated that 90% of all American passenger car trips are less than 40 miles. That distance is well within the range of current lead battery-powered EVs.

If we could achieve a target of, say, 15% penetration by electric vehicles into the U.S. transportation system by the year 2000, we would acquire our first means of storing and utilizing the excess electrical energy generated at night. Because most battery recharging would take place during the off-peak period, utilities would be able to more efficiently utilize their generating capacity over a full 24-hour period. As a result, 200-to-600 thousand barrels of crude oil would be saved daily by every 1,000,000 EVs on the road, according to Department of Energy figures.

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Electric Utility Energy Storage (Load Leveling)

Electric utility load leveling is the process by which excess electricity generated during off-peak hours is stored and then made available to supplement needs during peak demand periods. Such energy storage saves oil (in oil-fired plants) and lowers overall production costs. During off-peak hours, even coal fired and nuclear plants are often throttled back to inefficient levels. The power used in charging an energy storage system could keep these plants near full load and maximum efficiency continually, thereby lowering production cost. Peak loads are typically met with gas turbines and other fast-response oil-fired units. By displacing peak period generation from these units, energy storage would save liquid petroleum.

To better understand how liquid petroleum is used in this country, consider the following information. In 1979, 46% of the energy consumed in the United States was derived from liquid petroleum. Of this premium energy, 9.5% was used to generate electricity and 53% was used for transportation.

A significant portion of the 9.5% figure represents the utilities' use of liquid petroleum to keep up with the demand for electricity at peak times. It is an energy-inefficient solution, which is becoming more expensive with each passing year.

According to projections published by the electric utilities, this unnecessary energy expenditure will amount to about 100 million barrels of oil per year by 1985 and climb even higher in the years to come. The use of lead acid battery storage systems to handle peak loads could cut this consumption to the bone. Electric utility researchers estimate that if load leveling systems were put in place throughout the nation's power grid by the year 2000, approximately 750 million barrels of petroleum equivalent could be saved annually. Of course, such a projection will be met only if the necessary development of energy storage systems continues at its present pace.

Solar Energy Storage

Storage of energy generated from solar rays is a relatively new application, which could grow rapidly in the future. Like all emerging technologies, its growth potential is tied to the role government will play in research and development. In the case of solar, R & D is particularly needed in the area of improving photovoltaic panels. Batteries used in conjunction with photovoltaic arrays could provide either all or part of the power requirements of residential or commercial buildings. However, at present such systems would not be cost effective due to the high price of solar collectors. When high performance solar collectors become available at competitive prices, lead acid batteries for energy storage can be the prime energy storage link in the photovoltaic chain.

Energy Storage System Technology

The leading candidates for energy storage systems used by electric utilities between now and the year 2000 are pumped hydro, compressed gas and batteries. Other storage systems that hold promise for the long-term include thermal energy, super conducting electromagnetic fly wheels, and advanced chemical energy storage. But these are little more than gleams in the eyes of researchers at this date, so we'll focus on the more readily at hand systems.

Pumped Hydro

As the term implies, pumped hydro involves using off-peak energy to pump water into a natural or man-made reservoir. As electrical demand approaches its daily peak, the water is released to power hydro generators. While pumped hydro plants are feasible, it has been determined that such facilities must be built on a large scale

to be economically viable. As a result, constructing such systems would entail huge capital costs and long lead times. What's more, proper sites for the massive plants would be hard to find and be subject to severe environmental constraints. Given those parameters, there appears to be little justification at this time for basic research and development funding for pumped hydro.

Compressed Gas

Compressed gas energy storage works on the same principle as pumped hydro, but utilizes air instead of water as a storage medium. Its major advantage over the water system is that compressed gas can be squeezed into smaller geologic formations than can water, making it suitable for use on a larger number of sites. While such systems have been under study for years, the only operational data on the compressed gas technique comes from a single plant in Huntorf, West Germany, which has been in operation since 1978. Since there are no such plants operating in the United States, experts predict that compressed gas cannot make a significant contribution to energy storage before the year 2000.

Batteries

Of the total energy that can be conserved today by energy storage, it is estimated that 25% can be saved by load management, 15% by pumped hydro, and the largest portion, 60%, can be saved by batteries. Lead acid storage cells could provide the additional advantages of easy siting, flexibility of size and capacity, and rapid availability for installation.

The key ingredient in the further development and commercialization of energy storage is a battery of suitable performance, ruggedness and cost.

At the present time, and for the foreseeable future, the lead acid battery is the only practical, efficient and economical rechargeable energy system available. There are five main reasons why lead acid batteries excel today:

1. They have a basic cost advantage over other systems.
2. Peak power capabilities are excellent and can be further improved at low states of charge with added refinements to electrolyte circulation systems.
3. Projected energy density levels are sufficient for most applications and are far more likely to be achieved than those claimed by developers of other systems.
4. The lead acid battery industry has manufacturing know-how obtained over many years, and its production facilities are on-stream to accommodate ongoing battery improvements.
5. Of all battery types, the lead acid lends itself best to efficient recycling.

It is important to note that it takes considerably less energy to produce refined lead than it does to produce nickel, zinc, or iron -- metals which form the base material used in several types of more exotic batteries now on the drawing board. For example, it takes about 60 million BTU's of energy to produce a ton of zinc. Primary lead requires about 27 million BTU's per ton of product, or less than half as much energy.

Lead is also a readily available and recoverable resource -- a resource that is not under the control of a foreign cartel and a resource with an in-place infrastructure which permits rapid and economical commercialization and deployment of high performance lead acid batteries.

Recognizing the suitability of batteries for energy storage, the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) have sponsored programs to develop the technology of advanced batteries, including lead acid, for energy storage systems.

Advanced battery systems are expected to play a major role in reducing the dependence of electric utilities on petroleum based fuels by the year 2000. However, the existing lead acid system, with ongoing R & D, is available now as the nation's premier energy storage system.

The effects of past R & D funding have produced these breakthroughs:

A. Near-Term Electric Vehicle Batteries

The pace of development of electric vehicle batteries in the United States is largely determined by "The Electric and Hybrid Vehicle Research Development and Demonstration Act" (PL 94-413), as amended by PL 95-238. This legislation calls for development of improved batteries for EV applications. A major aspect of the program, as put in place by DOE, is the development of "near-term" EV batteries, or Improved State-of-the-Art (ISOA) batteries, as well as "advanced" EV batteries.

The Department of Energy near-term battery R & D program is being carried out through the Argonne National Laboratory (ANL). Eight industrial developers participated in the effort, sharing the cost with the government. These R & D efforts have been supplemented by independent battery characterization testing at ANL's National Battery Test Laboratory (NBTL).

The performance objective for the near-term battery program can be gauged using the term specific energy, which is the watt-hour capacity per unit of weight (wh/kg). Before government funding of the R & D of near term batteries, the lead

acid battery specific energy was generally accepted as under 30 wh/kg. In boosting performance parameters, the DOE program established specific energy levels for the Improved State of the Art Battery (ISOA) at 39 wh/kg and for the advanced battery system at 55 wh/kg.

As of early 1980, a ISOA lead acid battery developed under the program achieved a specific energy of 41 wh/kg, which constitutes a 39% improvement over conventional system performance. Obviously, government R & D funding with supporting funding by industry has more than achieved the optimistic goals initially set. The long term goal for the advanced lead acid battery which is scheduled to be met by fiscal year 1984, appears to be achievable, provided the needed funding continues to be provided. However, if Federal R & D dollars are reduced, the lead acid battery industry alone may not be in the position to expend the necessary monies to achieve this goal, given the existing state of the economy and the uncertain state of the market for these batteries.

B. The BEST Facility

As part of the Department of Energy program, the concept of a Battery Energy Storage Test (BEST) facility was born. Recognizing the need for an intensive investigation of how batteries perform in electric utility load leveling applications, a pilot plant was established through the cooperative efforts of DOE, EPRI, and a major New Jersey electric utility, Public Service Electric and Gas (PSE&G). The project is another example of private industry working in unison with the Federal Government to conduct the type of R & D that will ultimately find solutions to the national energy problem.

With the knowledge that storage batteries have the potential for achieving the necessary technical performance and cost goals, BEST was created to evaluate experimental battery modules in prototype energy storage systems. The facility

quickly made its mark as an essential element in the overall national energy storage development program.

The significant goals that BEST is achieving were made possible by the Federal Government's willingness to work hand-in-hand with private industry. Unfortunately, an extension of the BEST concept was among the first programs cut under recent budgetary rollbacks at DOE. The program, known as Storage Battery Electric Energy Demonstration (SBEED) was scheduled to put the concepts learned at BEST to a full-scale test at a working utility. Ideally, SBEED would have proven, once and for all, that lead acid batteries have what it takes to handle on-line load leveling. But the data and operating experience that could have been gained were lost due to the DOE cuts.

In spite of reduced governmental support for battery R & D, the industrial sector is conducting such research on its own, though at a much reduced level. The lead industry, through the International Lead Zinc Research Organization, Inc. (ILZRO), is spearheading this effort.

The ILZRO project is aimed at developing improved energy density, capacity, and cycle life in lead acid batteries. This is being augmented by other projects relating to improved design, construction and performance, as well as fundamental research. We will not go into the technical details of these programs, but we can summarize some of the significant developments. Pilot production of improved types of lead oxides, which constitute the heart of the lead battery system, has been accomplished. Deep-cycling tests of these oxides have been successful. In all, more than 20 new types of oxides have been tested and their efficiency continues to be evaluated. It is expected that a modification of one or more of these oxides will help produce a battery system with performance characteristics that exceeds those of DOE's present ISOA cell.

The Importance of Continued R&D Funding by the Government

The storage program of the Department of Energy was created to develop technologies that would assist the private sector in supplying reliable, economical, safe, and environmentally acceptable energy storage. In that vein, the program represents the nation's first opportunity to free itself from overdependence on imported energy sources.

Despite its relatively short history, the program has made significant strides toward that goal. However, as we have pointed out throughout this statement, more needs to be done. Therefore, it would be neither prudent or logical to cut back on such a vital program while it is in its prime. Continued Federal funding in this area will help ensure the creation of a technology base which will be available to industry to further develop much needed energy storage systems.

It follows that if the research and development funding is curtailed by Government, the establishment of the necessary data base and the incentive for industry to develop the necessary products and systems will be lost or much delayed. The R & D accomplishments to date, which have just begun to provide the information needed to expand the technologies of energy storage, would also be negated or significantly deferred.

Impact of the Total Withdrawal of Government R & D Funding

The complete withdrawal of Government-sponsored R & D could constitute a severe blow to key factors in the development of American energy storage technology, as based on the lead acid battery. We realize there are many other systems that might -- at some future date -- be as good as or perhaps better than the present lead acid battery energy storage system. However, most of these systems exist only in the laboratory

development stage, while others appear so costly that they are not likely to become commercially viable.

The elimination of the only system that is currently workable -- the lead acid battery -- without a suitable replacement for a 10-year period, would leave the United States increasingly vulnerable to any and all pressures that the oil exporting nations could bring to bear.

Industry recognizes the need for its participation in the commercialization of new products and technologies. But it is appropriate that government share funding of the basic research that will turn the conceptual ideas into a reality. From these R & D roots, industry can proceed on its own to produce and market a commercially viable product. The lead battery energy storage system could be such a product, but only if the Federal Government has the foresight to see its promise.

Affiliation

Lead Industries Association, Inc. is the market development and information organization of the North American lead industry, promoting uses of the metal through publicity programs, educational activities and technical services. The non-profit trade association is supported by producers and consumers of lead, both in North America and throughout the world.

University of California

LOS ALAMOS SCIENTIFIC LABORATORY

Post Office Box 1663 Los Alamos, New Mexico 87545

In reply refer to: CTR-9-5719
Mail stop 464

December 3, 1981

Honorable Manuel Lujan, Jr.
1323 Longworth Building
Washington, DC 20515

Dear Congressman Lujan:

Transmitted herewith you will find our submittal to become part of the record for the December 8, 1981 hearing before the Subcommittee on Energy Research and Production of the Committee on Science and Technology. We appreciate the opportunity provided by the solicitation of your 11-30-81 letter. I believe we have thoroughly responded to the four items of that letter and have also provided some supporting information.

We very much appreciate your personal efforts on behalf of the SMES program and the many committed persons who have dedicated themselves to this very interesting technical challenge.

Sincerely,

John D. Rogers

JDR:lps

Enc: Superconducting Magnetic Energy Storage (SMES) Program Submittal

cc: J. Liersch
L. Germain
H. Dreicer
W. Quinn
J. Rogers
CRM-4 (2)
File

SUPERCONDUCTING MAGNETIC ENERGY STORAGE (SMES) PROGRAM

by

John D. Rogers
Los Alamos National Laboratory
November 24, 1981

INTRODUCTION

The following statement is submitted for the record for the hearing before the Subcommittee on Energy Research and Production of the Committee on Science and Technology of the U.S. Congress.

The Superconducting Magnetic Energy Storage (SMES) program relies on the natural phenomenon characteristic of certain materials that become superconductors and show no resistance to electrical current flow in liquid helium near the temperature of absolute zero. This physical phenomenon is used to build inductive energy storage coils, more commonly called magnets, to store energy at high currents and fields at many tens of thousands times the earth's magnetic field with little or no dissipation of the stored energy.

Several highly interrelated magnetic energy storage programs that rely on applied superconductivity are underway in the U.S. with appropriate Department of Energy support. Historically, these are the large electric utility diurnal load leveling concepts studied at both the University of Wisconsin and the Los Alamos National Laboratory and the electric utility transmission line stabilization SMES unit being developed by the Los Alamos National Laboratory for installation in the Bonneville Power Administration (BPA) system. Both programs have been under the sponsorship of the Office of Energy Systems Research, Division of Energy Storage Technology and the Division of Electrical Energy Systems, with varying levels of participation in the past several years. A third magnetic energy storage program that is related to the SMES work is the pulsed energy storage effort for fusion systems under the Office of Fusion Energy. Two projects are underway, one at the Los Alamos National Laboratory and the other at the Argonne National Laboratory. The fusion superconducting energy storage program is to induce current in tokamak plasmas for ohmic heating and to provide equilibrium magnetic fields to stabilize the plasma in space. Technology exchange among these programs is quite high; however, this submission is to present the application, potential, and work for SMES with respect to electric utility applications.

A fourth emerging interest in magnetic energy storage for electric utility application is to close a power loss time window for some critical defense facilities for the interval between loss of public utility power and the start of power flow from local generators. SMES systems can respond to power demand in 6 to 10 milliseconds. Ten to fifty megawatt-hour (MWh) SMES systems could meet the military power loss need. Such systems are more nearly the size of the BPA electric transmission line SMES stabilizer unit than the large diurnal load leveling SMES systems but would more nearly be like diurnal load leveling SMES in structure.

ROLE OF THE LOS ALAMOS NATIONAL LABORATORY FOR SMES

The role of the Los Alamos National Laboratory in the development of SMES has been principally twofold. The laboratory has made the only integrated reference point design of a large diurnal load leveling SMES system. This study includes a conceptual design of all subsystems ranging from superconductor and magnet to dewar, refrigerator, liquid helium storage, vacuum system, underground excavation and tunnel preparation for locating the dewar and coil for structural support to bedrock, and electric power conversion equipment. This work is also the only comprehensive technical design of its kind with extensive cost factors and is now being used as a reference for the recently funded Electric Power Research Institute (EPRI) study discussed below.

The Los Alamos role has also been to design and be responsible for bringing to a very advanced hardware state a small SMES system for an alternate capability to damp unstable power oscillations on the BPA high voltage AC transmission lines from the state of Washington to southern California. This SMES system is the first major application of applied superconductivity in a U.S. electric utility system. Installation in the BPA Tacoma Substation, under joint Los Alamos - BPA supervision, is scheduled to start June 1982 with experimental operation scheduled for October 1982. Actual functional utility operation is expected to occur beginning February 1983.

BENEFITS OF SMES

SMES has the capability of storing energy and offers a high availability with efficiency of 90% as compared to efficiencies of 40 to 70% for other energy storage systems. The amount of energy stored depends only on the size of the SMES system. Because of the fact that the energy is stored as electro-magnetic energy that is available almost instantaneously, within a few milliseconds, SMES performance is unique. For this reason, any size SMES system can respond to stabilize power oscillations on transmission lines. Large SMES systems can provide energy for diurnal load leveling over periods of hours and at the same time provide the equivalent of spinning reserve to replace emergency loss of generating capacity. SMES is one of the most flexible energy storage systems available for electric utility applications.

Diurnal load leveling SMES offers the possibility of saving millions of barrels of oil annually by replacing intermediate expensive oil fired generated power with energy generated from coal and fission power plants.

Small SMES systems, by damping unstable power oscillations, can enable larger amounts of power to be transmitted up to the design thermal limit of transmissionn lines. This increased transmission capacity can delay or eliminate the need for installing additional transmission lines to save millions of dollars. There are at least fifteen long, over 400 miles in length, electric transmission lines in the free world countries and at least six in communist countries that might benefit from SMES stabilizer systems. Not all these lines are currently identified as having unstable power oscillations. Even some short length lines are known to have stability problems.

Intermediate size SMES systems can provide power for 30 to 60 minutes to close a possible power loss window for critical operations. Such a SMES system would be of a size to serve also as a prototype for a large diurnal load

leveling SMES. Such a scaled prototype will be a necessary technology development step before a large diurnal load leveling SMES is built.

DEVELOPMENT AND TECHNOLOGY STATUS AND NEED

Diurnal load leveling SMES systems have undergone conceptual technical design studies. The EPRI study, mentioned above, will establish the competitive economic SMES position. After this sequence of events, serious experimental component research and development must be undertaken in real geometry configurations. This component development must be done in parallel with a detailed engineering design, probably of a 30 to 50 MWh prototype diurnal load leveling SMES, to guide the work. The step after the component development is to build the prototype and to operate it in a mode as a proof of principle experiment.

The transmission line stabilizing SMES system is 70 to 90% complete and must be installed and operated to complete the experiment. This will run through FY83 and will exhibit to the utility industry a viable technology ready for industry adaption.

PROPER ROLE OF GOVERNMENT

The state of art of SMES is such that the research and development is rather well advanced for small transmission line power stabilization and the experiment must be taken to completion. Because of the extended nature of the present commitment, the completion of the experiment should be funded by government. The risk is reasonable. The cost of the technology transfer to industry would be comparable to the cost of completion and the delay to accomplish technology transfer without completion of the presently planned work would be much greater than the time for Los Alamos and BPA to complete the work.

Large diurnal load leveling SMES is within the conceptual state of the art but requires considerable unusual and demanding research and component development. The risk is relatively high and not likely to be undertaken by the conservative utility industry. Regardless, the potential for oil savings is great and warrants a long range effort. The role of government is to support the need as presented in the preceeding section on Development and Technology Status and Need through the construction and operation of the 30 to 50 MWh prototype diurnal load leveling SMES. Then the experiment will be ready for industrial integration into large scale 1,000 to 10,000 MWh utility application.

GENERAL DETAILED DISCUSSION

Energy storage to meet the diurnal load leveling requirements of the typical electric utility would have a capacity of 1,000 to 10,000 MWh and a power delivery rating of 250 to 1250 MW. A SMES system to meet this power rating and storage capacity might measure 300 to 1,000 meters (about 1,000 to 3,300 ft) in diameter. Large SMES systems for diurnal load leveling would be about 90% efficient because they store energy as electro-magnetic energy and no energy state conversion is required, that is, there would be no intermediate energy state for storage or conversion such as thermal, chemical, or mechanical as encountered in thermal energy storage, batteries, pumped hydro, compressed air, or flywheels. Each type of storage has its own area of optimum application. Studies have shown that SMES has a great competitive potential for useful energy storage for large electric utility diurnal load leveling systems.

The high efficiency and unique fast response capability make SMES an attractive energy storage concept. SMES units will be charged during low demand periods at night from base load fission and coal fired power plants and return the stored energy to the electric grid during daytime high demands periods. Intermediate and power peak shaving generating capacity will be displaced with the potential of millions of barrels of oil saved. One study projected an annual saving of 320 millions of barrels of oil for a 20% penetration or replacement by the year 2020 of only the gas turbines used for peak power generation.

Conceptual design studies of diurnal load leveling SMES systems have been performed by both the Los Alamos National Laboratory and the University of Wisconsin. The Los Alamos National Laboratory has completed an extensive point reference design with a cost analysis for 1,000 and 10,000 MWh SMES systems, and the University of Wisconsin has concentrated on high current superconductor development, superfluid helium heat transfer, and conductor structural support. EPRI has contracted with Bechtel and General Atomic to perform an eighteen month study of diurnal load leveling SMES to determine its competitive economic position for electric utility energy storage.

Small SMES units can be used to stabilize power transmission on long high voltage lines and thus allow higher power transmission and/or delay the need for the installation of additional expensive power lines. The BPA operates two 500 kV, ac transmission lines, collectively called the Pacific AC Intertie, and one ± 400 kV, dc transmission line, the Pacific HVDC Intertie, that connect the Pacific Northwest and southern California. During the spring and early summer, in the interest of energy economy, excess hydroelectric power generated in the Pacific Northwest, is transmitted to the summer peaking southern California area, mainly Los Angeles, thereby replacing an equal amount of oil fired generated power. At high power transmission rates, predicted undamped power oscillations of 0.35 Hz (20 cycles per minute) occurred on the AC Intertie. BPA has controlled these oscillations by modulating the power flow from the ac system by use of the ac-dc converter supplying the HVDC Intertie. This control enabled the power transmission capacity of the AC Intertie to be increased from about 2,100 MW to near 2,700 MW. The 30 MJ, 10 MW SMES unit to be installed at the BPA Tacoma Substation during FY82 and placed into operation during FY83 has been developed by the Los Alamos National Laboratory. This unit will be an alternate or backup stabilizer to the present BPA method of stabilization and will function when the HVDC Intertie is out of operation. The HVDC Intertie availability is about 85 to 90% and was out of operation for six months from earthquake damage in 1974. The 30 MJ, 10 MW SMES unit, as a backup stabilizer, will pay for itself in six months of operation with the maintained high transmission rate of hydroelectric power to southern California.

The 30 MJ SMES BPA transmission line stabilizer is a high technology experiment with the hardware in a 90% ready state. The control software is in a 70 to 80% ready state. Installation at the Tacoma Substation is scheduled to start 6-1-82 with experimental operation to begin 10-1-82 followed with actual BPA utility operation for field evaluation and acceptance to run from 2-1-83 through 9-15-83.

Major components for the 30 MJ SMES system, designed and/or manufactured by industry, are the 30 MJ superconducting coil by General Atomic (California), superconducting wire by Magnetic Corporation of America (Massachusetts), superconducting cable by New England Electric Wire (New Hampshire), converter by Robicon (Pennsylvania), power transformers by Niagara Transformer (New York),

auxiliary transformers and protective dump switch by General Electric (New York), helium refrigerator by Koch Process Systems (Massachusetts), SCRs and uninterruptible power supply by Westinghouse (Pennsylvania), and nonconducting fiberglass reinforced, epoxy plastic dewar by Fiberglas Design (California), truly an integrated national effort.

Besides the potential military application to close a power loss time window now being explored, three technology spin-off applications for the electric utility industry are under consideration by the Los Alamos National Laboratory. These are a superconducting reactive power compensation unit, a superconducting fault current limiter, and a superconducting dc transmission line filter. All three devices will reduce power consumption of existing conventional utility components. The fault current limiter is now undergoing a cost analysis and design study by Los Alamos. All the concepts presented in this submission represent high technology not likely to be pursued by industry without prior proof of principal experiments.

corporation *America's Comfort Conditioning Company*

November 13, 1981

The Honorable Ron Williams
The United States House Of Representatives
Subcommittee For Energy
Research And Production
Rayburn Building, Suite B374
Washington, D. C. 20515

Dear Mr. Williams:

It is our understanding that a hearing is to be held November 17, and 18 to consider future funding for Electric Thermal Storage Programs in the future.

TPI Corporation has been designing and researching Thermal Storage in ceramic cores since 1976 and are the only U.S. manufacturer of this type of system. We have spent considerable monies in attaining the present State of the Art and from this we have determined additional areas of research which must be accomplished before the Electrical Thermal Storage is a viable product in the American Market.

This research must be accomplished in the area of brick which comprises the core and insulation which retains the energy within the core for efficient use when needed. The completion of this work will determine the success or failure of the Electrical Thermal Storage Concept within the U.S.

Since we are the sole manufacturer within the U.S. we have no other possibility of funding or help within this area than that by ORNL and the Federal Government. TPI Corporaiton cannot fund this research within a reasonable time to insure that the answers are available when the Power Distributors are ready to extend usage of the Thermal Storage Systems to increase their efficiencies.

We know that use of Electrical Thermal Storage Systems at the Off Peak Period will increase the Coal Fired Plant efficiency and uses wasted generating capacity within the nuclear system. It will extend the time period needed to find adequate alternate energy methods.

P. O. Box T - CRS *Johnson City, Tennessee 37601* *615/282-4131*

90-261 O—82——16

Honorable Ron Williams
The United State House Of Representatives
Subcommittee For Energy
Research And Production

November 13, 1981

Page 2

Therefore, we urge the Committee to give all due consideration to extending the funding for this research.

If TPI Corporation can be of assistance in providing any needed data for your consideration, please contact us.

Sincerely yours,

TPI CORPORATION

Jerry Lawson
Director Of Engineering

JEL/jbl

STATEMENT OF
NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION
to the
ENERGY RESEARCH AND PRODUCTION SUBCOMMITTEE
OF THE HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY
OVERSIGHT HEARING ON
DOE ELECTRIC SYSTEMS AND ENERGY STORAGE RESEARCH AND DEVELOPMENT
Washington, D.C.
December 8, 1981

Mr. Chairman and Members of the Committee: My name is Lowell J. Endahl, manager of Research and Technological Development for the National Rural Electric Cooperative Association (NRECA). We appreciate the opportunity to present the NRECA membership views with respect to the U.S. Department of Energy activities in Electric Energy Systems and Energy Storage.

Specifically we would like to comment on the continued need for funding for energy storage and electric systems research being planned or performed by the Department of Energy, Division of Electric Energy Systems and the Division of Energy Storage Technologies. We are deeply concerned that the importance of this aspect of DOE research is constantly underestimated--and consequently underfunded. It, more than any other research sponsored by the Department of Energy, has direct value to the electric utility industry and to the public because of its economic and national security implications.

NRECA is the national service organization which represents nearly 1000 non-profit, consumer-owned rural electric systems which deliver electric power to approximately 25 million people in the rural and sparsely populated agricultural areas of 46 states. These small cooperatively-owned electric utilities are located in about 2,600 of the nation's 3,100 counties, and they own and operate more than 40% of the distribution line in the nation to serve about 9% of the population.

At the last annual meeting (March 3-6), attended by more than 10,000 people (mostly directors and managers of rural electric systems), these rural electric cooperatives adopted a series of resolutions on issues of concern. One resolution, adopted at several regional meetings for consideration at the next annual meeting, pertains to the apparent attitude of the present administration that energy research is the total responsibility of the private sector. This resolution states as follows:

Federal Responsibility for Research

> We are concerned about the apparent attitude of the Administration that the responsibility for investing in, and conducting energy research (including costly short and long range projects) should be turned over completely to the private sector. There seems to be a general feeling that utilities and other types

of industry have capital readily available to carry out such research for the benefit of the nation -- without government support.

Rural electric cooperatives are ready and willing to carry their fair share of the burden -- and they have been participating in major research efforts by their contributions to the Electric Power Research Institute. But the electric cooperatives and other segments of the utility industry are already shouldering a major burden in providing for the energy needs of the nation. Additional costs, whether for high cost capital, increased environmental requirements, unnecessary regulatory costs, or for research, must be passed along to the consumer.

We respectfully urge the Administration and the Congress to initiate a stepped up energy research program which ultimately can help stabilize energy costs.

The above resolution expresses a universal concern of electric utilities over the nation. They are facing tremendous financial pressures, and are curtailing all "unnecessary expenditures" and deferring other costs just to stay in business.

We see among the rural electric systems a real desire to participate as full members of the Electric Power Research Institute (and many are full members) but many are financially unable to do so. In some states the public service commissions are indicating a greater unwillingness to permit research contributions to EPRI to be included in the rate base for consumers. Because of limitation of funds, EPRI has had to curtail or delay and reschedule some of its planned research.

Now we see a determined effort by the administration to eliminate an important phase of research apparently with the idea the utility industry will fund it. We believe that utilities have reached the limit in taking on additional financial burdens. And yet, the research that is being managed and conducted by the Electric Energy Systems group is exactly the kind of research that can result in greater efficiencies and future savings for consumers.

Rural electric systems have a special interest in a number of specific projects that have been managed by the Electric Energy Systems Group.

Electric Energy Systems and Energy Storage

Since rural electric systems own and operate over 40% of the electric distribution line in the nation and serve in the sparsely settled areas of the country where wind and solar energy systems

are likely to be popular, they have a special interest in the research being performed by the Department of Energy in Electric Energy Systems and Energy Storage.

A host of new problems are beginning to surface for rural electric systems as small power producers and cogenerators, with all types of power generating equipment (i.e. wind, solar, biomass and hydro) seek to sell their surplus energy to the cooperative utility. All utilities are required to purchase this energy from the qualifying producer under PURPA Sections 201 and 210. While rural electric systems are willing to purchase this self-generated energy of their members, the problems connected with the integration of small quantities and intermittent sources of energy into the utility grid can be difficult and uneconomical. Resolution of such problems involves development of energy storage, and also research on the technical electrical and safety issues of producing acceptable utility quality power. We are pleased that DOE has instituted and conducted research projects pertinent to the interface and storage problems of small power producers, and feel that this work needs to be continued and expanded.

A major research effort is needed to develop low-cost integration and storage equipment in order that solar, wind, and other supplemental energy sources can produce utility power economically. We recommend that the Electric Energy Systems budget for System Architecture and Integration work be funded at approximately $8 million, in order that this type of research be expedited and information made available promptly.

Rural electric systems strongly support the research work underway on Extra High Voltage (EHV) Transmission and studies relating to electric field effects (resolution attached). Recent experiences in acquiring right of way and constructing EHV lines have revealed serious misconceptions, mystique, and fearfulness on the part of the general public as to the electric field effects on vegetation, animals, and even people living near EHV lines. Results of the research work underway are urgently needed.

We have gone on record in the past supporting storage battery research for utility applications. In particular we have recommended support for the SBEED project which was being conducted in cooperation with Wolverine and Northern Michigan Electric Cooperatives. It now appears that this project has been terminated as a result of budget reductions by the DOE under the Reagan Administration. We would urge this committee to authorize the reinstatement of this activity in the FY-82 Budget at a level of $4 million. The electric cooperatives involved in this activity do not have the resources to continue the project in absence of Federal support.

We are also concerned with dramatic budget cuts planned or implemented in other energy storage activities. Of particular

concern is future support for work on Compressed Air Energy Storage (CAES) systems. Past efforts by the Department of Energy have contributed significantly to the decision by Soyland Power Cooperative to construct the first CAES plant in the United States. Soyland's commitment to this technology would not have been possible without the confidence rendered conventional CAES by research conducted by the DOE in past years.

DOE's current activities in CAES are confined to research and development on the behavior of porous rock CAES reservoirs and advanced CAES systems which promise greater fuel savings, higher efficiencies, greater load management flexibility, and significantly improved economics. R&D in these areas is a high risk commitment for private parties because of the lack of a developed market and high R&D investment costs. The confirmation of the stability of porous rock reservoirs for CAES, especially at elevated temperatures, is one of the goals of the planned CAES Field Test at Pittsfield, Ill. and is essential to future development of CAES in aquifers. Development of second generation CAES systems will be delayed for many years if federal research support is not provided. We, therefore, encourage this committee to continue funding of CAES research at a level of $2 million in FY-83 and to be diligent in its overview of DOE efforts during FY-82.

NRECA member systems recognize that a great many smaller scale storage systems currently undergoing research and development by DOE will significantly improve the potential of electric load management and affect schedules for future generation capacity additions. Storage for seasonal and diurnal energy demands are recognized to have significant potential for reducing both peak electrical demand and consumption of petroleum. We, therefore, encourage this committee to continue Federally supported research in seasonal and diurnal, thermal and electric storage technologies.

The rural electric cooperatives of this nation realize that the Committee and Congress are trying to hold down excessive expenditures in an attempt to produce a budget with a smaller deficit. We commend you for that. In this statement we have suggested action which would continue important electric energy systems and energy storage activities at funding levels which are less than or equal to that expended in these programs in prior years.

DOE Electric Energy Systems currently manages some $46 million worth of energy research programs which includes energy storage research as well as other important research in electric field effects, bulk power transmission, and the problems related to interconnection of dispersed energy sources. We respectfully request that the DOE Electric Energy Systems research budget be continued at a level no less than $30 million.

It is important that this utility oriented umbrella type of program be continued because it has economic and national security implications. Our ability, as a nation, to move large

amounts of power safely and efficiently over high voltage transmission lines; and conversely to utilize dispersed generation and energy storage effectively in times of emergency is of greater importance today than ever. To wipe-out that portion of research that concerns itself with these issues cannot be in the national interest. In addition, there are many economics to be achieved by greater attention to improved, more efficient methods of distribution of electricity.

In addition to funding, we also urge the committee to exercise its oversite responsibilities with respect to DOE organization and the role of electric energy systems research. Electric Energy Systems, like an orphaned child, lacks a home. It has, over the past several years, been bounced from the Office of Coal Research to Conservation, then Solar, then Resource Application, and back to Conservation.

The electric utility role in national security and in the economics of this country is too important to be relegated to secondary status. We respectfully request that the umbrella electric systems R&D work be reorganized to report directly to the DOE Undersecretary in order that it can be properly and effectively coordinated with all other DOE energy research.

We thank you for the opportunity to express these views.

RESOLUTION

SUBJECT: Extra High Voltage Transmission Line Research

The increased use of extra high voltage (EHV) overhead transmission lines for transmitting electric power by rural electric cooperatives is essential if we are to continue to provide the electric power needs of rural America. Recent experiences in acquiring right of way and constructing such EHV lines have revealed serious misconceptions, mystique, and fearfulness on the part of the general public as to the electric field effects on vegetation, animals, and even people living in close proximity to such EHV lines.

Although such concerns are not supported by scientific evidence, we have an urgent need to provide positive, scientifically demonstrated evidence that there are no significantly adverse effects upon vegetation, animals and people living in close proximity to such EHV lines. NRECA urges the Congress and the Department of Energy to adequately fund the electric fields research work being conducted by the DOE involving both alternating and direct current overhead EHV lines and disseminate such information to the public.

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ROCKET RESEARCH COMPANY
A DIVISION OF ROCKDOR

November 12, 1981
Ref. No. 3200-82-004

Mr. Ron Williams
Subcommittee on Energy Research
and Production
Committee on Science & Technology
Room B-374
Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. Williams:

In order to introduce new technology into the marketplace, a need for change must exist. Obvious? Perhaps, but by itself need is not a sufficient motivator for the bulk of the market. Risk, whether real or perceived, and economics are principal factors that determine whether or not and at what rate existing and future need is serviced by new technology.

To be sure, other factors influence a decision to adopt a new technology; however, they are invariably subjugated in importance to risk and economics. A new technology may fulfill a need with adequate or better economics, but if it is sensitive to an unstable regulatory climate, if the application is the first of a kind, or especially if it is much of a departure from past practices, its risk will be perceived to be high; hence, a questionable investment from the industrial management and financial community's point of view.

Needs exist today that will, by all indications, grow with passing time. These needs are for reduced or at least stabilized energy costs and for reliability of energy supply. Both of these needs are favorably impacted by conservation measures. In general, throughout U.S. industry, most of the simpler measures either have been taken or are impending. Future measures to be applied will, increasingly, depend upon new or evolving technology.

The industrial manager's incentive to evaluate new technology under current conditions is minimal. Investment tax credits supplemented by the energy tax credits provide one important form of incentive as do tax-exempt forms of financing where available. The likelihood of the latter type of financing for a high-technology and/or first-of-a-kind project, however, is slight. Furthermore, tax credits are only available after a project is committed or in service and are thus not an incentive to making the first decision to evaluate the technical and economic feasibility of a new approach. What is needed is assistance at this early decision stage to encourage new technology application assessments.

An excellent example of such an implementation strategy may be found in the California State Agricultural and Forestry Residue Utilization Act of 1979 wherein a sizeable revolving fund was set up to co-fund energy recovery projects within the scope of the act. When the project is on-stream and meeting predetermined performance criteria, the State funds are paid back by the project

owner for use again. If the project should fail to perform, the owner has the option of retaining ownership and instituting the necessary fixes or removing the equipment, in which case the State retains title. With the first option, payback is still made. With the latter option, there is no payback. This approach significantly reduces the risk to the plant management of implementing a new technology and encourages societal goals at the same time.

Research, development and demonstration activities of the type supported by the Conservation Division of the U.S. Department of Energy have also been, and hopefully will continue to be, important in instigating equipment development and adoption of a variety of new technologies. DOE support of feasibility evaluations and teaming of industrial, research and financial organizations in new ventures has provided considerable incentive and credibility in the demonstration and adoption of new energy technology.

An example of successful long-range, high-risk technology development carried on by DOE is the Rocket Research Company chemical heat pump/chemical energy storage system. This is a high-technology device that affords a potential for annual energy savings of approximately 35 million barrels of oil when fully utilized in industrial, commercial and residential applications. The system uses sulfuric acid and water as the working fluid. This media is alternately distilled with a reject or solar heat source to separate and concentrate its components which are then recombined to produce heat. Its process constitutes a thermodynamic cycle that provides a temperature amplification from inlet to outlet which is the heat-pump principle of operation. If energy storage is desired for an application, supplemental tankage is provided to retain the separated working fluid components after distilling.

Development of this technology began several years ago with a 25,000-Btu/hr engineering test unit. At present, under DOE sponsorship through Brookhaven National Laboratories, Rocket Research Company is testing a 150,000-Btu/hr laboratory test unit which incorporates energy storage and which will function in both a heat pump mode and a building-heating/energy-storage mode. This unit is scheduled for continued testing through fiscal year 1982. Requirements analyses in the present work have shown that industrial heat pumping is the nearest term application for the equipment and that the range of sizes of interest to an industrial user extend upward from a 1-million-Btu/hr rating or a scaleup of over 6 to 1 from the present state-of-the-art.

The technology factors and hardware scaleup required to achieve an industrial performance level have led Rocket Research Company to propose such a design and industrial field test program to DOE for initiation in FY-1982. Federal funding is vital to sustain the evolution of this important energy-saving technology since the cost attendant to the continued development of the industrial size units is significant. Private funding for this activity is unavailable because there is no industrial operating experience that certifies the chemical heat pump performance predictions, economics and equipment safety. Successful field testing will alleviate these risks and permit the initiation of a privately funded commercialization plan, which will in turn be greatly

enhanced by present and planned incentive programs. The estimated funding required for the proposed industrial development and field test is $660,000 and present indications are that funding for this field test has been discontinued. If Federal funding is unavailable, there is a high probability that development will be terminated after the 150,000-Btu/hr unit tests due to the risks previously cited.

In summary, the chemical heat pump program illustrates how Federal involvement in a high-technology project that has substantial long-range, energy-saving potential is acting to reduce the front-end risk that would otherwise preclude its development with purely private capital. Continued Federal funding through the proposed industrial field test phase is urged to attenuate the remaining risk sufficiently to permit commercialization with private funds and to provide the opportunity for incentive programs already in place to work.

Yours very truly,

ROCKET RESEARCH COMPANY

Bruce W. Schmitz

Bruce W. Schmitz
Vice President, Engineering &
Technology

bam

cc: Duane W. Lundahl
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ROCKET RESEARCH COMPANY INFORMATION PRESENTED TO THE
U.S. HOUSE OF REPRESENTATIVES SUBCOMMITTEE ON
ENERGY RESEARCH AND PRODUCTION

The decision-making policies concerning government spending for research and development should comprise three elements. First of all, the proposed R&D program should represent a technology which has a high potential for meeting national goals. Next, there should be a degree of risk or uncertainty associated with developing the new technology with the amount of government/private cost sharing in proportion to the degree of risk. Finally, the R&D program should be preplanned in phases so that the proper transition to commercialization by private or local interests can be achieved at a time when the benefits balance the risk. With this type of planning, new technologies can be rated to determine the level of government involvement. For example, if the proposed R&D effort involves application of a proven technology from a given industrial sector to a new process for another industry, the risk would be minimum and government support should not be involved. In this example, with current policies of accelerated equipment depreciation, tax credits and fuel price decontrol, successful commercialization can occur rather quickly. However, if the new technology involves unproven concepts or processes, then the risk and expense of commercializing is often so great that the idea is abandoned or the time to achieve full commercialization is longer than desired to meet the national goal or requirement. In this case, the government can assist the R&D effort to ensure that national goals can be met within the necessary timeframe.

To illustrate these points, two case studies of highly beneficial government participation in energy technology development and application are presented. In the first case, a product with high technology content and thus high technical risk is being developed. In the second case, the application of a technology proven in Europe is being pursued in a new U.S. social and regulatory setting with the added risk factor of utilizing an unproven but commonly available energy source.

CHEMICAL HEAT PUMP/CHEMICAL ENERGY STORAGE SYSTEM R&D

Chemical heat pumps represent a new technology base with the ability to substantially reduce the consumption of energy in the industrial, commercial, and residential sectors. These devices provide an ability to recapture low-grade heat rejected from buildings and industrial sources and to reuse the heat at increased temperature levels for comfort and water heating or in a process. Chemical heat pumps operate with up to 15 times less electrical power and in higher temperature regimes, thus affording significant performance advantages over conventional heat pump designs. An additional advantage is that energy storage can be incorporated because of the working fluid selection so that intermittent energy sources, such as solar energy, can be utilized. It has been conservatively estimated that chemical heat pumps can eventually displace 0.2 quads (35.7 million barrels of crude oil) annually. The distribution of this energy is equally divided between utilization of reject industrial process heat and commercial/residential solar driven heating and cooling units. This reduction of crude oil consumption represents a reduction of foreign imported oil equalling 1.2 billion dollars per year (at $35/barrel*).

PROGRAM STATUS

Rocket Research Company (RRC), a division of ROCKCOR, Inc., has been under contract for system development of the sulfuric acid chemical heat pump since 1976. Figure 1 summarizes the programs sponsored by the Department of Energy (DOE) totaling $1.3 million to date, including the current four-task Phase III contract being funded through Brookhaven National Laboratories (BNL). In the present effort, Tasks 1 and 2 are completed and consisted of a requirements analysis and a detailed design of a 150,000-Btu/hr verification test unit (VTU) using commercial design practices. Generic applications have been identified which include industrial heat pumping using reject heat, space conditioning, air or gas moisture removal, steam accumulation, cogeneration, and energy storage. The VTU design permits evaluation of two of the most

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* Reference "Energy User News," February 2, 1981, page 25.

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PROGRAM STRUCTURE

H_2SO_4/H_2O CHEMICAL HEAT PUMP/CHEMICAL ENERGY STORAGE SYSTEM

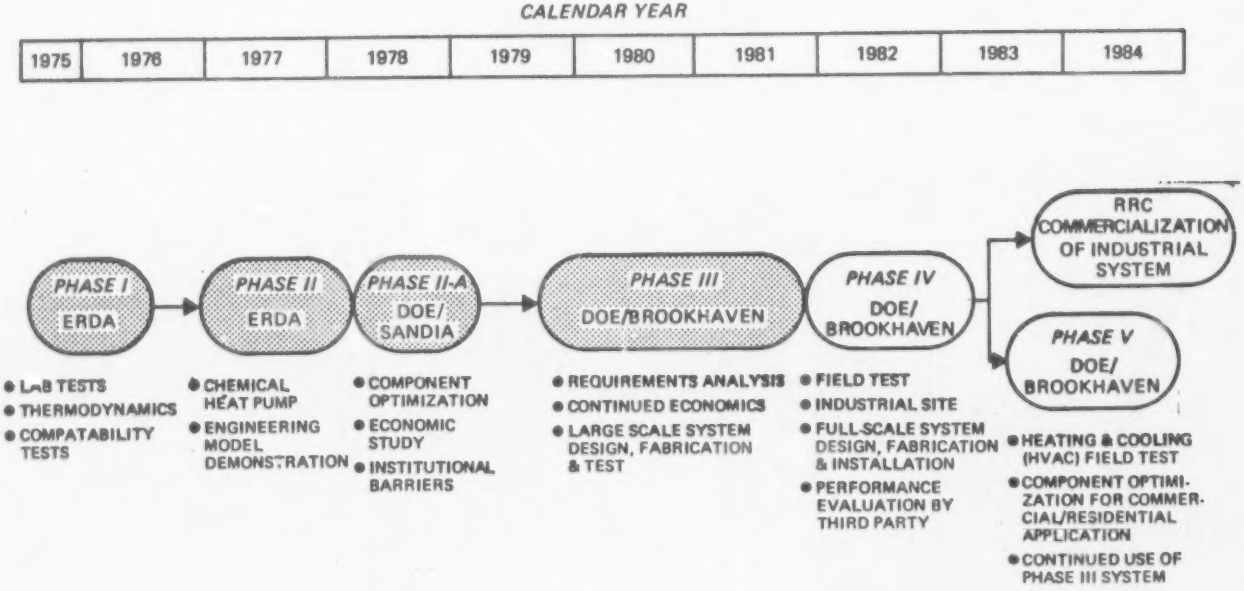

Figure 1

promising near-term applications: waste heat pumping and space conditioning. The remaining Tasks 3 and 4, consisting of VTU fabrication and testing, respectively, are being conducted in FY '81.

SYSTEM DESCRIPTION

The chemical heat pump system is a high technology device. It can be configured to operate as either an energy storage device, or as a heat pump, or both. In its operation, a working fluid of concentrated sulfuric acid is diluted with water yielding heat which is then used for space (comfort) heating or for a process. The diluted working fluid is reconcentrated by distilling, using a reject heat source such as from an industrial process. Solar energy may also be used as an input energy source to drive the system. Because of the thermodynamics of the cycle, temperature amplification is achieved in its operation. Thus, with the heat pump, low-quality reject heat streams can be upgraded and restored to productive use, for example, in an industrial process. If the operational cycle is interrupted after the working fluid is reconcentrated, the chemicals can be retained in separate tanks until the user requires more heat. This latter case is an example of energy storage. In practice, heat pumping and energy storage can be provided in a single unit if required by the application.

Figure 2 is presented without explanation simply to illustrate the complexity of the concept and to underscore the highly technical nature of one selected design. Figure 3 shows the developmental state of the device in the present engineering unit used for laboratory testing at the 25,000-Btu/hr output level. Under the present Phase III contract, a 150,000-Btu/hr test unit will be evaluated in FY '81. In the proposed Phase IV field test described in the next section, a 1 million-Btu/hr heat pump unit will be designed and tested at an industrial site. The Phase IV unit is sized to be in the minimum range of interest to an industrial user and represents a 40-to-1 scaleup from the experimental unit of Figure 3.

Heating and cooling of buildings and residences which includes energy storage continues to be an important application of the chemical heat pump. However,

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INDUSTRIAL CHEMICAL HEAT PUMP

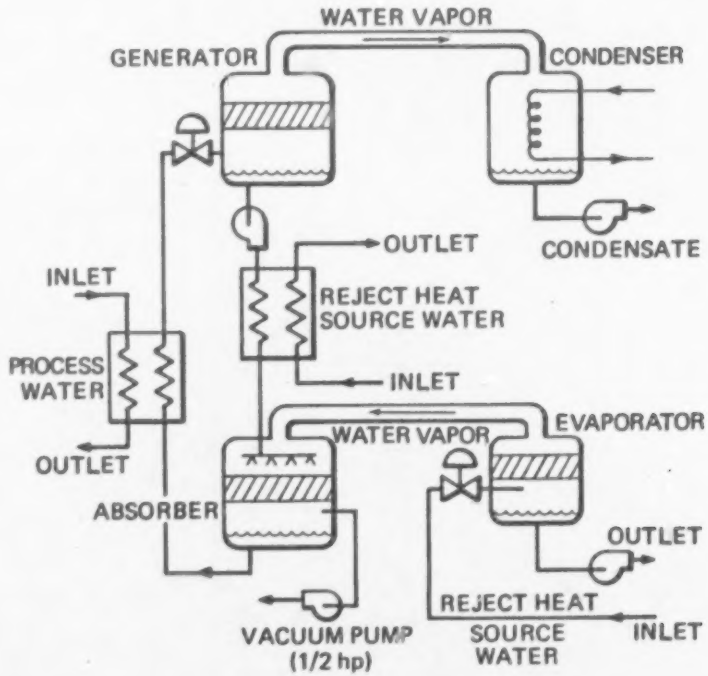

Figure 2

CHEMICAL HEAT PUMP/CHEMICAL ENERGY STORAGE SYSTEM

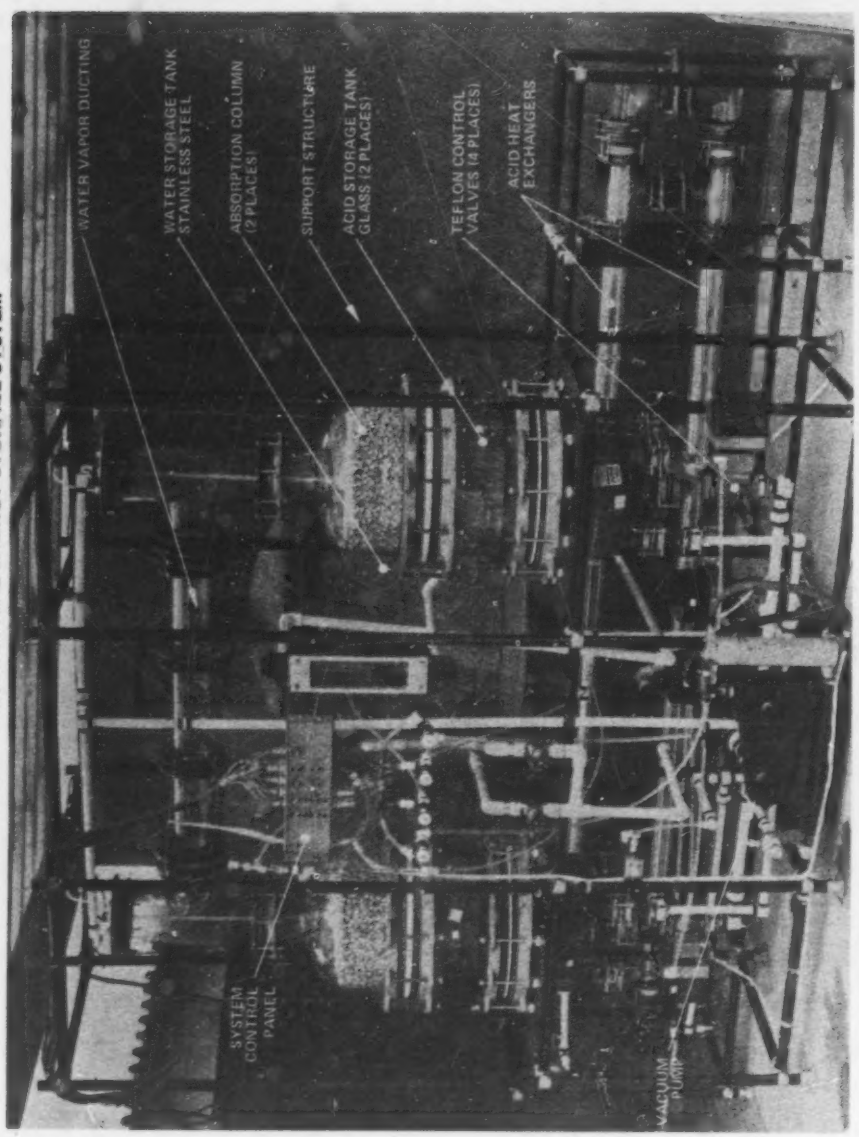

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Figure 3

the system requires a longer development period due to its added complexity. Therefore, the industrial heat pump has been given near-term priority for R&D.

FUTURE PLANS AND PROGRAM RATIONALE

An industrial field test program is presently being planned for implementation during FY '82 (Ref. Figure 1, Phase IV). The program will consist of the design, fabrication, and testing of a chemical heat pump having an industrial capacity (about one million Btu/hr). The test will be conducted at a representative industrial plant and operated by plant personnel. The objective of the proposed program is two-fold: (1) design a full-size industrial chemical heat pump using scaling parameters evolved during previous development and (2) evaluate the technical and economic performance of the sulfuric acid system at a representative industrial site. The acquired information will serve as the basis for technical and economic performance projections for a wide variety of industrial applications of chemical heat pump technology. The proposed field test program cost is estimated to be $660,000, not including cost sharing.

This industrial test program is necessary before commercialization can occur because there is no industrial or public operating experience that certifies the chemical heat pump performance predictions, economics, and equipment safety. This is the risk. Public and industry acceptance will be positive if these factors are determined with field testing. Without a Federally funded field test program, the risk of commercialization due to this lack of operating experience is considered too great to proceed with industrial company funding alone. Future plans should also incorporate efforts to field test a solar-driven chemical heat pump/chemical energy storage system for residential and commercial use to maximize the range of applications and, thereby, the energy savings potential of this technology.

REASONS FOR CONTINUED FEDERAL FUNDING

With the information gained from field test units to reduce the aforementioned risks, a commercialization plan can begin which will be greatly enhanced by the administration's policies of more rapid depreciation of equipment, tax

credits and fuel price decontrol. The decontrol of fuel prices may or may not significantly increase the incentive to commercialize since the net effect of deregulation may be to stabilize energy prices. Since chemical heat pump economics are favorable compared to today's energy prices, RRC does not feel that decontrol will be a negative incentive to commercialize.

At the present time RRC is concerned that funding planned for the recommended field testing may be discontinued. This funding is needed to overcome the risks cited above. If funds are unavailable, the expected result is that the path to commercialization will be considerably lengthened with a real possibility that development will be stopped completely. Considering the potential energy savings in imported oil, combined with a modest cost to the government for R&D, RRC believes the current and projected DOE-funded program plan for chemical heat pumps, when carried through field testing, is extremely cost effective and will result in a significantly shorter time to achieve full commercialization as well as aid in assuring that commercialization will occur.

THE BELLINGHAM DISTRICT HEATING SYSTEM DEVELOPMENT

Since 1977, a project has been underway to develop a district heating system for the City of Bellingham, Washington. The project is sponsored by the U.S. Department of Energy Division of Solar and Thermal Energy Systems, Office of Advanced Conservation Technology and administered through Oak Ridge National Laboratories. At the present time, the project is entering Phase III (Ref. Figure 4), which is the last phase in which DOE funding is planned. Phase IV is the full system implementation which will be financed locally and which includes planned partial payback to DOE for R&D equipment installed during Phase III activities. Lead investigation work for the project to date has been conducted by Rocket Research Company (RRC), a division of ROCKCOR, Inc. Support is being provided at no cost to the government by Intalco Aluminum Corporation of Ferndale, Washington, and by the City of Bellingham. Costs of Intalco and city activities are provided as cost-sharing to the project by each organization.

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PROGRAM OVERVIEW
BELLINGHAM DISTRICT HEATING SYSTEM
UTILIZING RESIDUAL HEAT FROM INDUSTRY

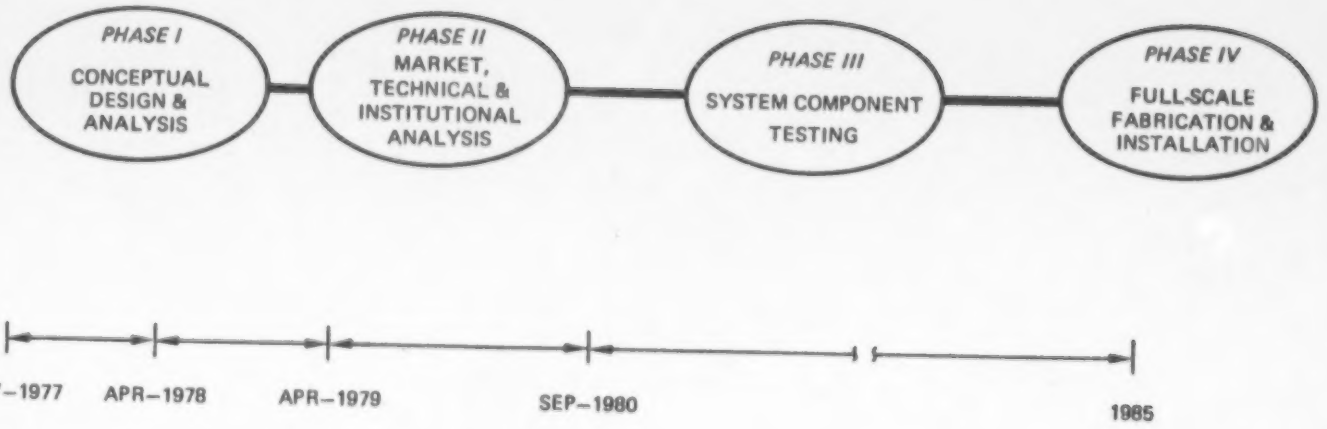


Figure 4

In two key technical particulars, this project differs from most district heating systems developed previously in Europe or presently under consideration in several U.S. cities. First of these is the proposed use of reject industrial process heat as the energy source and second is the plan to designate a service area where almost 80 percent of subscriber structures are single-family residences. Either or both of these characteristics are foreseen at many other candidate district heating sites as the technology spreads across the United States in the coming years.

Two other unique nontechnical features of this project are the inclusion of user retrofit costs as a capital expense of the system to encourage hookup, and an agreement by the City to repay DOE for portions of the R&D when the full-scale system is implemented. These features, as well as the two aforementioned items, combine to introduce an element of risk since the precedents are not well established in prior experience. Continued Federal funding support of this project through Phase III, therefore, is essential to project success to complete the risk mitigation process.

The following paragraphs develop the potential impact of this project on national energy consumption, the project plan, a technical description of the project, and the reasons why continued Federal funding is necessary when policy is changing to encourage more private involvement in energy conservation technologies.

NATIONAL ENERGY IMPACT

The Bellingham district heating project will utilize approximately 44 megawatts of reject industrial heat for the end use of community space heating and domestic hot water production. Full-scale implementation of this project will result in displacement of electrical, oil and natural gas usage equivalent to 200,000 barrels of oil annually. A few further statistics underline the potential national impact of this project. Energy utilized in the United States by the industrial base is approximately 40 percent of the total national energy consumption. In an industrial process, this heat is used and the temperature

reduced to a point where it has no further use within the plant, and thence is rejected to the atmosphere. About 85 percent of industrial energy consumption is eventually rejected in this manner. The rejected energy does, however, have sufficient utility to be applied to low temperature uses such as community space and water heating. Not all industrial reject heat can be feasibly recovered. Taking only that fraction which is recoverable with current-day technology, it is estimated that five to eight quads (5 to 8 X 10^{15} Btu) of energy (over 85 percent of which is oil and gas) can be displaced annually from the space and water heating demands of the United States using reject industrial heat. This represents over 1,000 million barrels of oil per year, or approximately 10 percent of the country's total annual energy demand. Actual gas and oil displacement would be about 2 to 3 million barrels of oil per day, or over 25 percent of oil imports. The potential benefits of widespread implementation of this technology are clearly significant and desirable.

PROJECT PLAN

The project began its first phase in 1977 (Ref. Figure 4) with a survey of the primary aluminum industry nationwide. The technical and economic results of this survey showed preliminary technical feasibility and preliminary economic viability, not only for the aluminum industry, but for all low-temperature industrial reject heat. District heating of homes and commercial establishments was identified as the most cost-effective application for the identified waste energy streams. In this concept, energy storage plays an important role by providing a buffer between the constant industrial reject energy supply and the varying community energy demand.

The city of Bellingham provides an ideal setting to unite the concept of district heating with the concept of industrial reject heat recovery. Bellingham has an unusually active citizenry taking a positive interest in community affairs. This factor was a strong contributor to Bellingham receiving an all-American city award from the National Municipal League, one of only nine such awards made nationwide. This citizenry has a demonstrated interest in environmental protection and energy conservation, which provides a good participation context for testing the energy-conserving technology represented by the hot water district heating system.

The city is located approximately 10 miles from the identified reject energy source. This distance is typical of many large industry/urban-core pairs in the United States.

The climate of Bellingham is relatively mild. The average annual heating season is 5,738 degree days, which is near the national average. More severe climates will show even better economic results; hence, Bellingham provides a conservative example site.

The present city administration is committed to revitalizing public housing and public service structures within the urban core. The proposed district heating system complements this activity and is thus in harmony with city renewal plans. The Mayor and City Council of Bellingham have placed this project and related energy issues on the public policy agenda, and thereby have given the project a continuity and political strength beyond what might be their individual political tenures.

During the second phase of the project, the example site of Bellingham coupled to Intalco Aluminum Company was examined in considerable detail. Key areas of investigation were (1) demographics of the market area, (2) equipment technology and supply, (3) additional energy sources, (4) institutional, legal and environmental conditions, and (5) more detailed economic evaluation. Each of these areas of investigation contributed additional accuracy to the performance and economic forecasts and institutional characterization, thereby improving the level of confidence in project feasibility and cost effectiveness.

Phase III of the project is underway presently. In Phase III, a small-scale district heating system will be installed in the selected service area to provide an assessment of the projected performance and costs and to serve as a community model to facilitate hookups in the full-scale system. This small-scale (100-structure) unit will become an integral part of the Phase IV full-scale (3,000-structure) system. In parallel, one of the eventual 12 full-scale reject heat recovery heat exchangers will be designed, fabricated, installed and tested at the Intalco plant to confirm its compatability with plant systems

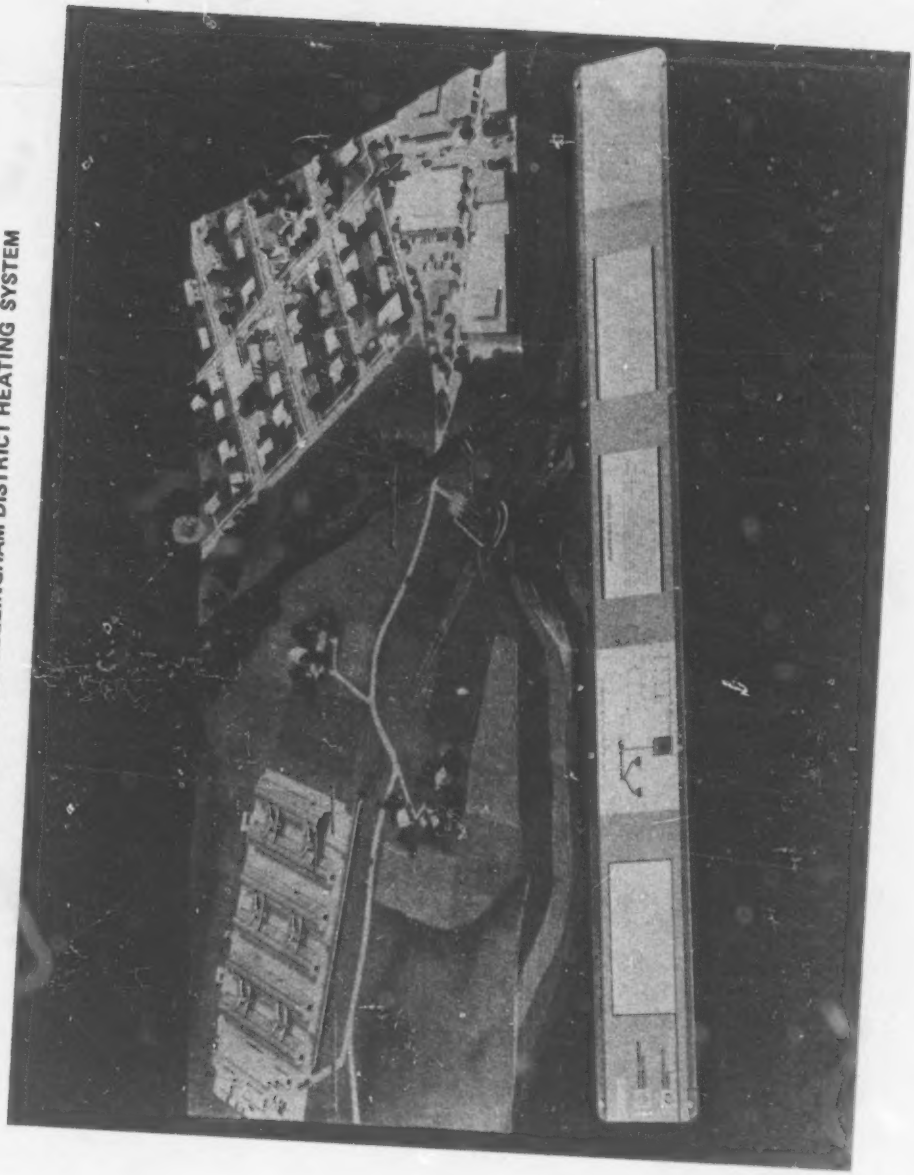
and operations and to validate its performance and costs. Further, selected detail engineering to support development of the bond issue in Phase IV will be completed. These activities will cover the next 39 months thus extending into FY '84.

Additionally, as a part of Phase III, Intalco and the City of Bellingham have executed a Memorandum of Understanding (Ref. Attachment A) with the Department of Energy detailing their support, participation, willingness to cost share, and payback provisions. The City has retained bond counsel and executed an agreement with national and regional investment banking firms to assist with developing a financing plan beginning with this early stage of the project. Legislation clarifying municipal ownership of a district heating system has passed the State Senate and is currently before the State House of Representatives. This legislation will facilitate implementation of the full-scale district heating system. Bellingham has established and staffed a district heating office. A community Advisory Group with diverse members of the community has been meeting for the last 18 months and continues to provide direction and linkage with major sectors of the public.

The fourth project phase will continue with city-arranged financing. A municipal utility will secure financing through the issuance of a mix of revenue and general obligation bonds to fund the full system construction. It is the stated intent of parties concerned that Phase III funds which are applied to hardware later incorporated in the full-scale system will be repaid from Phase IV revenues.

TECHNICAL SYSTEM DESCRIPTION

Figure 5 is a photograph of a semi-schematic model developed of the system. The proposed district heating system for Bellingham is based on the recovery of reject process heat from the production of aluminum at the Intalco Aluminum Plant (Figure 6) at nearby Ferndale. This reject heat will be used to heat water which will then be pumped to a heat storage and peaking boiler plant located near the Bellingham airport via an 11-mile transmission pipeline. The project



MODEL OF PROPOSED BELLINGHAM DISTRICT HEATING SYSTEM

29018-68

Figure 5

AERIAL VIEW – TYPICAL INTALCO POTLINE

29014-04

Figure 6

has placed special emphasis on evaluation of thermal energy storage alternatives to link the constant industrial heat source with the varying community thermal demand over time. In addition to the use of insulated surface tankage proposed for the baseline system, underground aquifers and an abandoned coal mine under Bellingham have been examined as candidate energy storage systems.

To provide for the small percentage of time that consumer heating demand exceeds available heat recovered from Intalco, and to provide a system backup, a fossil fuel-fired peaking boiler is included. Thermal energy storage will be utilized to minimize the consumption of fossil fuel by buffering normal swings in consumer heating demand. From the peaking and storage plant, hot water will be distributed to consumers in the community through a network of district heating mains, piping networks, metering stations and ancillary equipment. The Bellingham district heating system service area includes a variety of structures, many of which are single-family residences. To serve as many consumers as possible while optimizing distribution network costs, boundaries of the "baseline" service area were carefully drawn to cover structurally concentrated portions of contiguous neighborhoods.

REASONS FOR CONTINUED FEDERAL FUNDING

Although basic hot water district heating technology has been in use in Europe for a number of years, its transposition to the U.S. involves risks to the implementing parties. These risks arise in the present program in both the city of Bellingham and industrial energy source portions of the system.

The industrial partner, Intalco Aluminum, must be assured that the plant processes will not be adversely affected by the installation and operation of the reject heat recovery equipment. The aluminum reduction process must not be affected and the plant primary air pollution control system must continue to perform within specification. For both the industry and the city, the heat recovery equipment performance must be confirmed in the operational environment to provide the required utility-level confidence in the heat source availability. From the City's standpoint, to secure Phase IV financing, not only must the energy source be secure, but also the energy market which will provide debt retirement must be assured.

The Phase III program now underway on a cost-shared basis with DOE funding is designed to minimize or eliminate these risks to the satisfaction of all involved parties -- industrial, city, Federal and bond counsel. Interruption of the funding from DOE would stop the project due to lack of local funds to carry through this risk phase. Considering the exceptional nationwide energy-saving potential of this reject heat recovery/district heating technology and the need to encourage its widespread implementation, every effort should be made to assure continuity of funding of the Phase III work through DOE as presently planned.

J C Crawford
Director
Components and Standards

Sandia National Laboratories
Albuquerque, New Mexico 87185

December 3, 1981

The Honorable Manuel Lujan, Jr.
U. S. House of Representatives
Washington, DC 20515

Dear Congressman Lujan:

We welcome the opportunity to respond to your questions on DOE's Battery Storage Program. Battery Storage is just a part, but a significant part of your subcommittee's December 8, 1981, hearings on Electric Energy Systems and Energy Storage Systems. Specifically, battery storage is a component of Energy Storage Systems. Sandia's perspective is that of DOE's Lead-Center for battery technology development. Our qualifications for this role stem from over 30 years of experience in advancing the technology and design of batteries for nuclear weapons.

As you are aware Sandia has become deeply involved in a number of energy programs during the past several years, one program has treated "Batteries for Specific Solar Applications." More recently Sandia was asked to accept a larger responsibility as the Lead Center for all DOE battery technology development, and we will discuss this role in more detail later in this letter. We will now address your specific questions by dividing our response into three sections: "The Need for Battery Development," "The Need for Government Participation," and "Sandia National Laboratories' Role."

The Need for Battery Development

Why does the U.S. need to develop advanced batteries? In a word, to reduce dependence on imported petroleum. The "bottom line" for all major applications of DOE battery development is to reduce oil consumption. The general advantages of reduced dependence on imported oil are manifold and have been discussed at length over the past several years. We will describe below how a successful advanced battery development program can contribute to reduced dependence.

There are three major application areas for advanced batteries. First, to be considered is the electric vehicle or EV. It has been estimated that if just 10 million EV's are in use by the year 2000, oil savings will amount to 400,000 barrels per day. EV's provide other advantages. They offer considerable

help in the battle for clean urban air, as they are essentially pollution-free. While it is true that fuels must be burned in power plants that provide the electricity for charging the vehicles, these plants are generally outside the immediate urban area, and their emissions are more easily controlled than the emissions of thousands of vehicles. In addition, a large fleet of EV's would permit the electric utilities to operate more efficiently. This efficiency comes about because EV's would be recharged during the night when utilities have their smallest loads. Thus EV charging would improve the utilization of the large, efficient, "base load" plants, typically coal or nuclear.

The critical component in achieving a practical EV is the storage battery. Current batteries are too heavy, too expensive, and have too short a lifetime to provide an economic EV needed for mass markets. While near-term battery improvements may result in feasible EV's for limited applications, the mass market awaits a truly advanced battery.

The utility industry, besides benefiting from EV's, would also benefit very substantially and directly from their own use of battery storage. The Electric Power Research Institute (EPRI) estimates that if 70,000 megawatts of storage were installed by the year 2000, close to 1,000,000 barrels of oil per day would be saved. Battery storage would allow substitution of coal or nuclear baseload generation for oil which is widely used for daytime "peaking" generation. Storage allows extra energy generated in low-use nightime period to be stored in batteries for use later during peak time. This technique is called "load-leveling" and is the second major application of storage. Current lead-acid batteries are, again, too expensive, too short-lived, and require too much maintenance to be economically feasible. So while load-leveling batteries do not require the high energy density essential for EV's, they still must meet life-cycle cost criteria unavailable today.

The third major application area for advanced batteries can be loosely labeled as "solar." Storage batteries are clearly essential for "stand-alone" photovoltaic (PV) or wind generator installations, which have no other source of on-site power. In the U.S., this market does not appear to be a major one in the forseeable future, but such systems could develop into a sizeable export market. Stand-alone systems need batteries with low life-cycle costs, and especially low maintenance. As we have said, these do not exist at present.

A much larger potential market for "solar batteries" is in conjunction with utility-connected PV or wind systems. U.S. taxpayers have a large investment in these systems which need a storage

system to be practicable. Initially, small amounts of energy generated by PV and/or wind systems can be absorbed by a utility using their normal generating flexibility. Beyond some point, however, either the utility, the customers, or both, should install storage to accomodate large fluctuations in output resulting from the unpredictability of solar generation. This threshhold will vary from utility to utility, but is probably on the order of 10 percent. That is, when solar generation exceeds 10 percent of the system's total generation capacity, storage becomes highly beneficial to prevent solar technologies from hitting a dead end at this critical market penetration level--advanced storage technologies should be developed now. Again, the problem is that current technology does not meet the cost, reliability, and lifetime goals needed for utility and/or customer battery storage units.

To sum up, advanced storage batteries are essential in achieving EV's acceptance and, in turn, the large contribution they potentially hold for the nation in terms of displacing imported oil. Advanced batteries are also essential for utility load-leveling, and the widespread use of solar-electric technologies. Equally important, the best battery today (lead-acid) is deficient in one or more critical parameters for these applications.

The Need for Government Participation

While the need for advanced batteries has been described, it is probably less obvious why the DOE needs to support such work. After all, some very large potential markets have been identified. There are many reasons why totally private development is unlikely to succeed.

First, there is the nature of the present battery industry. This industry by and large produces lead-acid batteries, most of which go into automobiles. It is a mature industry, with a mature product. The benefits of mass production and production line efficiencies have been largely realized and the profit margin is small. Consequently, 90 percent of this industry's small R&D budget (1.7 percent of the net revenue from sales) goes into incremental product improvement, and only the remaining 10 percent goes for long-range research. Thus, little money is spent by the battery industry on development of advanced battery technology, and incremental improvements to the current mature lead-acid battery cannot produce the performance or economics required for widespread market penetration.

The most promising advanced batteries tend to be very different from the common lead-acid battery, which consists of

a plastic case containing multiple lead plates immersed in an acid electrolyte fluid. For example, the high temperature systems, such as sodium-sulfur and lithium-metal sulfide, operate at over 300°C with either molten reactants or molten salt electrolytes. The flowing electrolyte systems such as the zinc-bromine and zinc-chlorine are closer in character to fuel cells than conventional batteries. In flowing systems these electrolytes are pumped from tanks through reaction cells. These advanced electrochemical systems are foreign to much of the established battery industry, which has neither the funds nor a strong short term incentive to pursue these advanced concepts.

While these new types of batteries all show significant promise theoretically, there are major technical challenges and risks to be met before one or more commercial products could emerge. A major long-term commitment must be made to bring these batteries from the laboratory to the point where a technically and economically feasible product can be demonstrated. Only government has the resources and staying-power to bridge the gap from laboratory to industry. This does not mean, however, that the taxpayers are to hand industry a gift product several years down the road. The battery development program has always followed the philosophy that when an advanced battery has reached the stage where its future looks promising, cost-sharing development programs should be undertaken. In FY81 about 30 percent of the energy storage program was funded by industry. This participation insures a committed and able production source once development ends.

Another factor to consider when weighing the merits of government support for battery development is the issue of maintaining U.S. technological leadership. It is quite possible that the U.S. could wind up importing batteries whose aim is to displace imported oil! There are already aggressive battery programs in Europe and Japan. For example, Germany is now spending more [$22 million] on development of the the sodium-sulfur battery development than does DOE on all battery technology development [$20 million for FY82]. The U.S. battery program is currently in a critical period concerning government funding. Several promising battery technologies are at the stage where significant government support is needed to move from the small scale laboratory stage to a larger scale engineering stage, at which point industry support becomes possible.

All of the above factors have been considered by the Congress over the past few years and have resulted in several Acts which define and direct the role of government in battery development. The first was the Federal Non-Nuclear Research and Development Act of 1974 (P.L. 93-577,sec.6) which directed

the development of "advanced energy...technologies," including batteries. Others include P.L. 93-413 (Electric Vehicles,1976), P.L. 95-590 (Photovoltaics,1978), and P.L. 95-294 (Energy Security Act,1978). As a result, there is a considerable body of enacted legislation mandating current DOE battery development activities.

The Role of Sandia National Laboratories

Sandia became involved in the DOE battery program in 1979 when the Laboratories were asked to manage a new project called "Batteries for Specific Solar Applications" (BSSA). Some of the factors influencing the DOE decision to place this program at Sandia were large Sandia efforts in photovoltaics (PV) and wind energy, as well as Sandia's substantial capability in battery development for weapon applications. The BSSA program has funded the preliminary development of several new batteries, including the zinc-bromine flow battery at Exxon and the Redox flow battery at NASA/Lewis Research Center.

More recently, DOE has reorganized its Electrochemical Energy Storage program to reflect greater decentralization, as well as reduced overlap of responsibilities by the field organizations. Responsibility for all battery research and development has been assigned to two field "lead centers." Lawrence Berkeley Laboratory (LBL) is the "Lead Center for Technology Base Research." This means that LBL is responsible for all basic research on new electrochemical couples and basic cell research, as well as supporting research.

Sandia is the "Lead Center for Exploratory Technology Development and Testing" (known as the "ETD Project"). In this role, Sandia is to be responsible for engineering development and testing of advanced batteries for the three major application areas discussed earlier (EV's,load-leveling, and solar). Specific duties of the lead center include preparing recommendations to DOE for multi-year program direction and funding, preparing the over-all ETD budget, evaluating battery technology, directing development contracts, insuring timely reporting to DOE management and to the public, and technology development through in-house projects.

CONCLUDING REMARKS

Sandia sees its overall role as a servant of the nation, primarily to design nuclear weapons, the quality of which is second to none. More recently we have been asked to apply our skills to the nations energy problems. We seek to perform this new role in as an objective manner as possible, fully

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realizing our responsibility to the U.S. taxpayer. The U.S. taxpayer has a large investment in DOE's energy programs since the oil embargo of 1974, and we see battery storage technology as a key to optimizing the eventual utility of many energy technologies.

If the nation cannot afford further investment in renewable energy sources, it should at least consider continuing battery technology development as a means of maximizing the return on past taxpayer investments.

We would also like to say that the projections used above for illustration are, of course, based on assumptions about market development, energy availability, cost, new energy sources, etc. The projections will change as the assumptions change. However, if the country is ever to have the option of a sizable EV fleet in the future; if it is to have the option converting base-load generation to peak-load use; if it is to have the option of high market penetration of intermittent renewable energy sources and the attendant benefits these technologies can bring to our society, it must develop advanced battery technology to the point of technical feasibility.

Therefore, Sandia is committed to the development of advanced batteries as a means of providing future energy alternatives for the U.S. We will provide the necessary technical expertise to oversee the success of this program.

We hope that this adequately addresses your questions, and we remain available to supply supplemental information if you require it.

Respectfully,

J. C. Crawford
Director, 2500
Components and Standards

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CHRISTINE T. BEATTY
DIRECTOR OF GOVERNMENT RELATIONS
202-331-7757

December 7, 1981

The Honorable Marilyn Lloyd Bouquard
Chairwoman
Subcommittee on Energy Research and Production
Committee on Science and Technology
B-374 Rayburn House Office Building
Washington, D.C. 20515

Dear Madame Chairman:

Energy Research Corporation (ERC), a St. Joe subsidiary, is very much interested in your December 8 energy storage hearing.

In lieu of testifying at that hearing, which we understand is not possible, I would ask that the attached statement prepared by ERC be entered in the official Record of the December 8 hearing.

Thank you for your continued interest in this issue and for the opportunity to comment.

Sincerely,

Christine T. Beatty

CTB:ack
Enclosure

ENERGY RESEARCH CORPORATION

STATEMENT FOR THE RECORD OF

MARTIN KLEIN

VICE PRESIDENT, ENERGY RESEARCH CORPORATION

BEFORE THE

ENERGY RESEARCH AND PRODUCTION SUBCOMMITTEE

OF THE

SCIENCE AND TECHNOLOGY COMMITTEE

DECEMBER 8, 1981

Energy Research Corporation (ERC), located in Danbury, Connecticut, is a subsidiary of St. Joe Minerals Corporation and has been engaged in the research, development and manufacture of advanced secondary batteries and fuel cells for over 11 years. ERC is currently under a cost-shared contract to the Department of Energy through Argonne National Laboratories for the research and development of Nickel-Zinc batteries for electric vehicles. The success of this and related projects could have a significant impact on the reduction of liquid petroleum imports by the U.S., yet continued government support is now seriously in question.

Historically the United States Federal Government, with the limited exception of some basic research funded by the National Science Foundation, has supported mission-related research and development which has been deemed in the national interest. This includes defense, health, space and recently energy. Some countries support research and development across the board to maintain international competitiveness, and one could argue that in order to maintain the U.S.'s competitive technology such a policy should also be vigorously pursued. To the contrary, however, we are now faced with a proposed contraction of R & D support particularly directed at new and improved energy sources.

These advanced technologies could reduce dependence on foreign oil, reduce the balance of payments deficit, reduce pollution, reduce dependence on liquid fossil fuels -- a diminishing resource -- and maintain our competitiveness abroad.

Advances in energy storage in particular could make a significant contribution toward this overall effort. Numerous government funded studies have shown that an electric vehicle capable of 75 to 100 mile range between recharges could replace about 25 percent of the passenger cars currently in use today resulting in a significant reduction in the use of liquid petroleum. In addition, energy storage systems for electric utilities which would store energy in the off-peak hours and deliver the energy during daytime peak demand, could have a comparable liquid petroleum saving. Both of these missions are battery limited. State-of-the-art batteries do not offer a set of characteristics that are competitive even with current oil prices. Therefore, new and improved electrically rechargeable batteries are needed. This has been an identified goal of the Department of Energy's energy storage activities, and continued support by the government in these areas is required.

Battery R&D is by its nature a slow, time-consuming and costly process. Most secondary battery systems exhibit wear-out mechanisms that result in decay in performance only with extended use. Therefore, extensive life testing is a necessity. Progress can be rapid initially, but the rate of progress diminishes as life improves since it takes longer periods of time to evaluate new variables. This consideration, coupled with the uncertainties of the electric vehicle and utility energy storage market, makes the sole continual support of research and development by private industry on new battery systems for these applications highly unlikely. In today's environment of high interest rates and market uncertainty for new

products, private industry will not choose to support developments that will come to market 5 to 10 years in the future. The recently enacted R&D investment tax credit, while a help, will not be a sufficient enough incentive to focus research and development on energy related problems that are more than 5 years away from the market place.

Since unlimited funds will not be available, it will be necessary to focus future support. The delivery van application would not have a major impact on fuel use and should be left to industrial sponsorship. It appears that no electrically rechargeable battery system on the horizon will yield a full performance (250 to 300 mile range electric). It is unrealistic to expect to reinvent the full-performance passenger automobile. Development of a cost competitive battery in the 25 to 30-watt hour/lb class is possible (a two times improvement over state-of-the art battery) that will serve the 75 to 100 mile range electric. This could result in a market for 10,000,000 EV's by the year 2000 for multi-car families.

To be competitive with $2/gallon gasoline (a projected future price), the battery will have to exhibit a life cycle cost of approximately 5¢/mile ($\frac{\text{first cost}}{\text{battery life(miles)}}$). Furthermore, a passenger car does not have to be life cycle cost competitive on a one-to-one basis with its ICE equivalent.

The Nickel-Zinc battery system's characteristics have the best potential fit of all battery types to achieve the above goals. We have made significant progress on cost reduction of the Nickel-Zinc system but life improvements are required. A

proliferation of small R&D projects on this or other battery types will not yield the necessary results. What will be required is a central, well-organized, balanced program directed at:

1. Basic Research
2. Innovative Concepts
3. Iterative Improvements
4. Cell and Battery Engineering
5. Cell and Battery Testing
6. Production Engineering

I, therefore, believe that it will be necessary for the Federal Government to continue in its strong support of energy storage systems, particularly the Nickel-Zinc EV project. The success of these projects will reduce our dependency on the use of liquid petroleum and foreign sources of same, reduce the balance of payments deficit, reduce pollution of the environment, maintain the U.S. standard of living and private mobility in the event of a liquid petroleum embargo and maintain international technological competitiveness.

PETER J. VOGELBERGER, JR. President

TELEDYNE ENERGY SYSTEMS
110 WEST TIMONIUM ROAD
TIMONIUM, MARYLAND 21093
(301) 252 - 8220 TELEX: 8 - 7780

30 December 1981
Refer to: AEP-WCK-347

Mr. Ron Williams
Staff Member
Subcommittee on Energy Research and Production
U. S. House of Representatives
Room B-374
Rayburn House Office Building
Washington, DC 20515

Dear Mr. Williams:

For the past several years, Teledyne Energy Systems has been supporting the Department of Energy in the research and development of advanced electrolytic hydrogen production technologies. Although the funding has been modest, significant progress has been made toward improving process efficiencies without increasing capital costs. In addition, this funding ($100,000 per year average) has effectively served as seed money, and Teledyne Energy Systems has matched the investment in long-term research goals by redirecting some of our internal resources that would normally be used for near-term product improvement work.

The purpose of this letter is to encourage the Committee to continue to support the development of hydrogen technologies as a long-term investment towards energy independence, particularly hydrogen derived from renewable resources, and to recommend areas that should be continued in the field of hydrogen generation using alkaline water electrolysis. In this regard, we are hereby submitting the attached statement for the record in support of the Subcommittee Hearings held on December 8, 1981.

If you or your colleagues have any questions or comments on this statement, we would be happy to discuss them. Teledyne Energy Systems obviously has a parochial interest in electrolytic hydrogen production, however, we also believe that hydrogen will become an important energy carrier option in the future. Most people agree that the major role for hydrogen in future energy scenarios is after the year 2000. That is only 19 years away. Many countries are aware of the universal importance of hydrogen and its future role in energy. They have chosen to accelerate their efforts in developing hydrogen technologies at a time when the United States appears to be moving in the opposite direction.

We hope you concur that we should not allow this to happen and that you will continue to support work in this area.

Sincerely,

Peter J. Vogelberger, Jr.
President

dw

This statement is submitted to the U. S. House of Representatives Subcommittee on Energy Research and Production in support of the December 8, 1981, Oversite Hearing on the Energy Storage Research and Development Programs of the Department of Energy. Teledyne Energy Systems is a United States manufacturer of commercial electrolytic hydrogen generation equipment and is one of several companies working with the DOE over the past several years on the various aspects of hydrogen production. The purpose of this statement is to encourage continuing support for research and development in energy storage and production technologies, especially the hydrogen option, and to recommend areas where continued R&D in hydrogen production via water electrolysis would be beneficial.

Hydrogen is one of the more abundant elements in the world, however, it is not found in a free state. It is contained in many common everyday chemical compounds, most notably water and hydrocarbons. Although it is vital to almost all important combustion processes, it is presently used in elemental form primarily as a chemical feed stock. The majority of this elemental hydrogen is produced by reforming natural gas. Hydrogen can be manufactured from the other naturally occurring fossil fuels such as oil, coal and shale oil; however, the lesser quality sources tend to be hydrogen poor and, in fact, require hydrogen enrichment to be usable in present day energy systems as synthetic liquid and gaseous fuels.

Hydrogen can also be derived from water by splitting it into its basic elements through the application of electricity and/or thermal energy. Water splitting electrolysis equipment has been commercially available since the early 1900's; however, there has been little incentive for development of this technology with the abundance of inexpensive natural gas.

As an important chemical feed stock, hydrogen accounted for over 3% of the natural gas consumption in the United States in 1979. This demand is expected to increase by a factor of 3 to 6 over the next 20 years, depending upon the extent to which synthetic fuels from coal and shale come into use. It is also generally agreed that hydrogen will play a significant role in future energy systems as both an energy storage medium and an energy carrier. The only question appears to be when and how these applications will develop.

For example, hydrogen is an appropriate, attractive energy storage and distribution medium for energy from renewable sources. Many of these sources will be remote by necessity either because they are small and widely dispersed or because they are large and far from the end user. Hydrogen can be one of the most effective means for collecting and transporting this energy. The gas utilities recognize that hydrogen gas is compatible with existing gas distribution equipment and natural gas can be blended with up to 15% hydrogen without equipment modification even at the user end. The electric utilities also recognize that hydrogen can be an effective means for long term storage and long-distance transmission of their product. Base load power plants running continuously are much more efficient than peaking plants burning oil and gas. Hydrogen would allow them to store energy on a seasonal basis. Likewise, energy can be shipped long distance by hydrogen at one-third to one-tenth the cost of electricity distribution.

Cost considerations presently limit the use of hydrogen as an energy commodity, and the cost of both fossil and non-fossil hydrogen will probably continue to be higher than other fuels until a hydrocarbon limitation develops. Such a limitation may be realized by resource depletion, production barriers, and/or environmental restrictions. Thus, in spite of the reservations about the timing and rate of impact of hydrogen as a

fuel or energy carrier, there is a need for a deliberate and organized research and development program to study the basic problems that constrain hydrogen's contribution to the national energy economy.

Teledyne Energy Systems has been pursuing improvements in alkaline water electrolysis technology in partnership with the Department of Energy (DOE) since 1976. Although the funding level has been very modest it has been effective as seed money and a source of program organization and direction. In cooperation with the International Energy Agency, the overall program has been reasonably well structured and directed toward research and development with long term payoff.

In our program, there have been three approaches to improving the efficiency of the alkaline electrolysis process. First, an increase in the operating temperature from the current commercial practice of approximately 60°C to an intermediate temperature range of approximately 125°C, offers a potential voltage efficiency improvement of 10%. Second, improvements to the electroactive anode and cathode via alternative electrocatalyst materials or improved electrode structures offer between 15 and 25% voltage improvement. Finally, changes to the characteristics of the electrode separator offer potential savings of approximately 5%. The task of developing an improved electrode separator that is stable at the 125 to 150°C operating temperature range is the key to attaining an overall process efficiency of 85%.

As a result of this work, a new high-efficiency cathode material was identified and validated under test as providing a 10% voltage improvement with adequate life characteristics for commercial use. Several promising anodes and electrode separator candidates have been identified that appear to meet the performance goals; however, they are yet to be validated in a long term test.

At the present time there is essentially no continuing program in the United States to develop high performance, low cost electrolytic hydrogen generators of the size or type required to serve energy applications. We believe that, even though many consider this to be a long-term option, basic work should be sustained to develop the technology so that it is ready when needed and the U. S. can maintain a competitive position with respect to the other countries that have chosen to emphasize hydrogen such as Canada and Japan, and the European nations.

We would recommend the following tasks as key in this respect, in order of priority:

1. Continue basic electro-catalyst and materials research to improve process efficiency with emphasis on anode and cell separator development.
2. Develop large low cost high performance cell configurations.
3. Demonstrate the compatibility with renewable resources such as solar and ocean thermal energy.

Summary

There is no question that government spending must be carefully priortized, controlled, and reduced. This does not mean however, that the Federal government should not assume a leading role in long term-high risk energy research and development programs that cannot be justified by industry in terms of return on investment and participation. Long term is typically characterized by words like "the next decade" or "the next century." Ten or twenty years is a long time in terms of private investment, however, it is a relatively short time in terms of achieving energy independence.

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December 2, 1981

The Honorable Marilyn Lloyd Bouquard
Member of Congress
House of Representatives
Washington, DC 20515

Dear Mrs. Bouquard:

I understand that the Congressional Subcommittee on Energy Research and Production will be holding hearings on energy storage. I believe that it is absolutely essential for this country to maintain a vigorous federally supported research program on advanced batteries. Such batteries are likely to be used in electric vehicles as well as for temporary storage of electrical energy (load levelling). Currently available batteries are not adequate for either of the above goals. It is unrealistic to assume that industry will be in a position to support battery R & D at the required level of effort. The absence of federal support will result in the loss of US leadership in this area, and the likelihood that in the future we will have to import advanced battery technology from Japan and Western Europe.

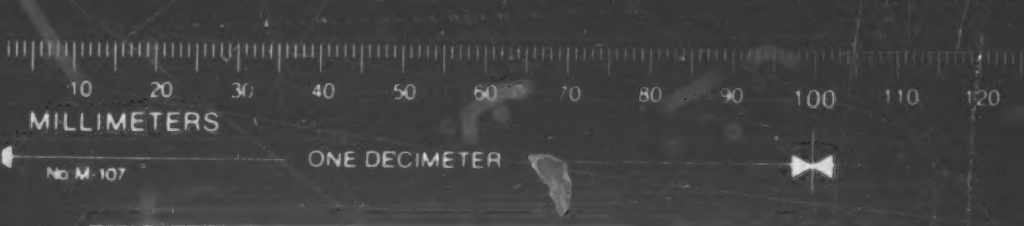
A vigorous program on advanced batteries requires trained electrochemists; such personnel are currently in very short supply. Cut-backs in federal support will result in even fewer scientists trained in electrochemistry.

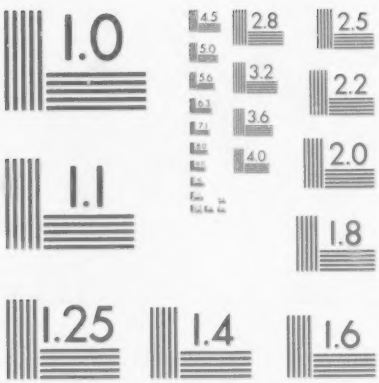
In conclusion, I am hopeful that Congress and the Administration will continue to provide funding for a vigorous R & D effort on electrochemical energy storage.

Sincerely yours,

Gleb Mamantov
Professor and Head

GM/rd





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